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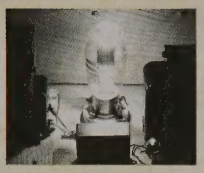

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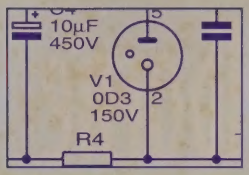

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UNIQUE POWER TRIODES

Volume 11 Number 2 1999

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GLASS AUDIO

Triode Power Amplifier 6C33C-B

BY DANIEL J.F. DAVID AND JEAN B. FORTIAS

PHOTO 1: The author's first stereo prototype amp.

On the day my friend Jean Fortias, a retired radio engineer who is mad about audio tubes, asked me to listen to his 6336A push-pull amplifier, my reservations about the revival of tube amplifiers subsided immediately. Its dynamics, transients, and presence made me reconsider my point of view of tube amplifiers, on which I had been trained in the late '50s, a training I never really had to use, since my professional career led me into a different field of electronics.

I decided to build my own tube amplifier (*Photo 1*), because Jean had convinced me that triode power with push-pull and without any negative feedback could achieve a level of bass and transient quality quite impossible for any pentode with negative feedback. He had placed on his amplifier a 12AX7 SRPP, a cathode phase-splitter device with an R120, and a driver with two other R120s that allowed him a low-impedance output and to connect directly into the push-pull power stage of the 6336A (US), superimposing both high voltages without (coupling) interstage capacitors.

Jean put at my disposal his extensive documentation, measuring instruments, equipment, and experience. I experimented with numerous designs, and built

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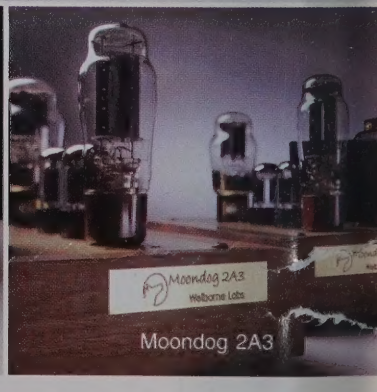

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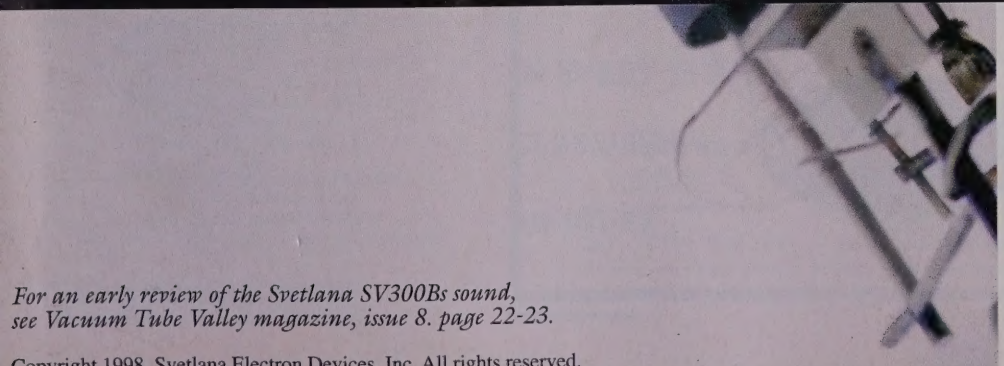

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For an early review of the Svetlana SV300Bs sound, see Vacuum Tube Valley magazine, issue 8. page 22-23.

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ABOUT THIS ISSUE

Our lead article in this issue relates a familiar tale: People tend to dismiss tube amps...until they get a good opportunity to listen, and soon they become converts. Such is the case with **Daniel David**, who was turned on to the good sound of audio tubes by his friend **Jean Fortias**, whose design is featured here ("Triode Power Amplifier 6C33C-B," p. 1). Join this duo from France in discovering the joys of designing and constructing a triode push-pull amp.

There's much more to good tube amp design than meets the eye. **Scott Swartz** provides us with a glimpse into the design process–with its compromises, rationalizations, and decisions that must be made. He follows up this design theory with circuitry description and detailed construction guidelines for building the second of the push-pull amps in this issue ("An SV572-10 Push-Pull Amplifier," p. 16).

Many of our readers have been calling for more projects for beginners. **Larry Lisle**'s modular approach to construction makes his amp design a suitable candidate. First you tackle the output stage and power supply, and once these are working, you add an input stage. Aside from its use here, the power supply will come in handy for other tube work ("An Expandable Beginner's Amp," p. 38).

Among audiophiles, the SRPP is a popular circuit, with unusual properties. To help us understand the characteristics of this circuit, **P. J. Touzelet** offers a theoretical analysis explaining its performance ("Theory of the SRPP Circuit," p. 44).

Finally, we present **John Stewart**'s "different" power amplifier circuit design to drive low-mu power triodes ("A Different Triode Power Amp," p. 50). We will follow up in a subsequent issue with yet another approach, covering filamentary and indirectly heated cathode versions. Stay tuned.

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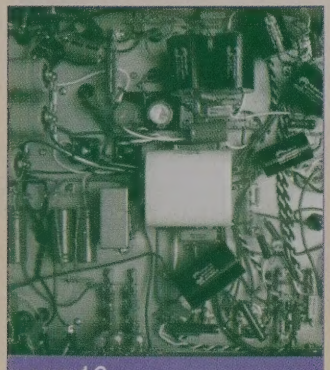

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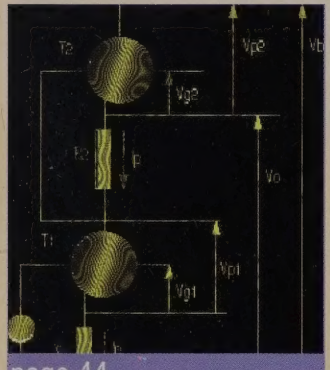

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EDITORIAL

Welcome, Newcomer

If I could, I'd really like to have a brief conversation with every new subscriber to this magazine. I appreciate your courage and anticipation in putting your money on the line to subscribe to an unusual publication about audio hardware. Maybe you know a lot about the subject, or maybe it is entirely new to you but you obviously hope to learn something about the technology that reproduces sounds.

If you *are* new to the technology, you may feel as though you just stepped into a room where everyone is speaking a foreign language. This isn't surprising, or shouldn't be. We *are* speaking a foreign language. Every special discipline has its own native tongue—a whole group of words, symbols, slang, acronyms, and technical gobbledegook which all the "natives" speak effortlessly, maybe leaving you confused and in the dark.

Well, first of all, remember that all of us—readers, authors, and editors alike—all started out just where you find yourself right now. And believe me, we are nothing special. We aren't beings from another planet, or a special breed with super brains who were born knowing Ohm's law and how to read those funny schematic symbols on every other page.

So please start out in your reading knowing that you may not understand a great deal of what you read—at least not the first time. But just keep on reading and rereading. Then keep a pencil and paper handy, to jot down questions which you will doubtless have. Put the date and time beside each question.

The next thing I hope you will keep in mind is that you will not find all the answers you need in this magazine. What happens here is based on a large body of knowledge which exists in what has been published here and elsewhere. Some (perhaps a lot) of it is in books. Some more is in journals published by professional bodies. Some of it is on the Internet these days (although this latter is sometimes a very mixed bag).

Many articles you will read here will refer you to other articles, or to books, or to websites. Follow up on those. I am not trying to sell books in this space, but we spend a lot of energy at this publishing company finding the books you may need to help you learn to enjoy this avocation fully. We've asked authors to take on the labor of producing some helpful books for people who need a place to learn the basics. More such books are in the works. Learning this hobby may be more like school in the early stages than you bargained for. Getting good at electronics is no more easy than learning any new skill—a new language, a new game, a new job.

Familiarize yourself with the "literature" of this avocation. You'll find it in catalogs: ours, and those of the vendors who advertise in this magazine. To me, readers too often consider catalogs to be merely places to buy things. A good catalog can be an education, or should be. I have learned an enormous amount about electronics and the hardware we use to make equipment, just by reading catalogs carefully.

We provide a couple of facilities to help with your questions. We invite your letters questioning what an author has written or designed. Send those along with an envelope addressed to yourself and we'll ask the author to help. Second, if you have a technical question that genuinely puzzles or stumps you, address it to our "Ask..." column, and we'll find someone among our authors who can answer. This latter is really a rich source of material for the magazine. A good question—something technical which puzzles you, however simple you may think it is—is highly valuable.

Please don't use this avenue to get someone else to do your work for you, however. Such as, "Please tell me which is the best 8″ driver for a subwoofer." Or, "Could you please suggest a crossover for Acme 5″ woofers and Xacto 1″ tweeters?"

The most important fact to keep in mind is that you *can* learn how to understand this hobby and how to enjoy it fully. You must not give up on yourself, and decide that you are too dense or lacking in ability to build your own electronic gear. I remember well how daunting it all seemed to me when I first began.

One of the best ways to learn is to just build something for yourself. Pick a simple project, get some parts and the tools you need: soldering iron, solder, side cutters, needle-nose pliers, some wire, and the needed parts. Take your time. Read and follow the instructions carefully. You might surprise yourself. If it doesn't work the first time, find out why it doesn't. Don't give up easily.

And be brave. Try it. If it blows up and you can figure out what your mistake was, you have learned something new—and valuable. One of my favorite stories is from a biography of that wonderful physicist of our time, Richard Feynman. He grew up on Long Island where his mother eventually got used to smelling smoke coming from the boy's room and knew he had done yet another experiment and was hanging out his bedroom window holding a metal wastecan from which smoke was billowing—yet another experiment gone wrong.

"What happens if I do this...?" are questions I see in some letters. Well, try it and see. You don't need an expert's approval to try a circuit two different ways. So you end up with a burned resistor or a failed vacuum tube. But most often I would bet you will not.

There is help if you really want to learn. Starting with our next issue I am instituting a new column for *Glass Audio*. There is a wealth of older material which appeared in the days when do-it-yourself was a regular part of everyday life, and I've resurrected some of the fine articles from the 1950s which will appear in each issue as "Audio Classroom." We'll start with a series on designing power supplies by Joe Marshall. These articles will also be available on our website. There will be other articles as well, including a series by the legendary Norman Crowhurst on designing power amplifiers.

Everyone must begin somewhere. And we are eager to be helpful to the beginner. Those of you who are advanced veterans may be tempted to become a bit restive with articles on the basics, but don't be too sure you know it all, either. I learned a new fact the other day from a letter by a knowledgeable reader. Maybe Marshall, Crowhurst, and others we will be publishing can fill in a few blanks for you as well. Fortunately, the adventure goes on for all of us. *Glass Audio* is here to help us find our way to better audio gear for every one of us, from the rank beginner to the most experienced.—E.T.D.

from page 1

many models so as to find the most satisfying solution for me, the main criteria certainly being the quality more than the power, the lowest level of distortion, and maximum dynamics with the widest bandpass.

Lucien Chretien, once Jean's teacher at the Ecole Centrale in Paris, had recommended in one of his books at the end of the '40s using a push-pull triode, doing away with even harmonics, a low level of odd harmonics, demagnetization of the output transformer by DC current, low internal resistance of the power tubes, and therefore a low output-transformer primary, making it easier to achieve better bass reproduction and eliminating the buzzing due to poor filtering. The described amplifier was equipped with push-pull 6A5 triodes without feedback.

DRIVER STAGE

The 6C33C-B (*Fig. 1*) requires significant swing. To obtain it with an acceptable distortion level—after quite a few experiments—I used SRPP connected directly to a cathode-follower SRPP, which gives a lower output impedance and produces bootstrapping on R_2. In that way I obtain a signal of 160V pk-pk for a DH of 1.3% odd harmonics and practically no even harmonics (*Fig. 2*). When operating this circuit at 480V DC, I decrease this harmonic level to its minimum and go out of this stage with 240V DC, which allows me a direct connection with the phase splitter.

The SRPP has well-known qualities: linearity, low output impedance, low distortion, significant gain, and under these conditions gives a bandpass of several hundred kHz.

PHASE SPLITTER

After trying many phase splitters on a model—paraphase, Schmitt, bicathode crossed, Lafon and so on—the "cathodyne" or balanced-charge phase splitter seems to be the most suitable in my application. It has no phase rotation and little distortion; moreover it allows a direct connection between itself and the SRPP, so there's no time factor between both levels, which was my aim.

I tried several tubes, including the 12AX7, 12AU7, 12AT7, 12B4A, 6080, 7233, and E88CC. Finally, after testing all of these, I chose the 12AU7. Because it has sufficient gain, its input impedance is high enough to avoid decreasing the input signal, and the output signal is strong enough when the two triodes are coupled (*Fig. 1*) to drive the power stage without an additional stage.

At this output level, I obtain a signal about 130V pk-pk, with a 1.25% DH, just sufficient to drive the 6C33C-B. A somewhat higher signal would have been better, but I would need to add an extra driver stage, with a higher distortion level. I tried using a 12B4A as a driver and a direct connection with the power stage by superimposing both high voltages.

The 6C33C-B push-pull is difficult to

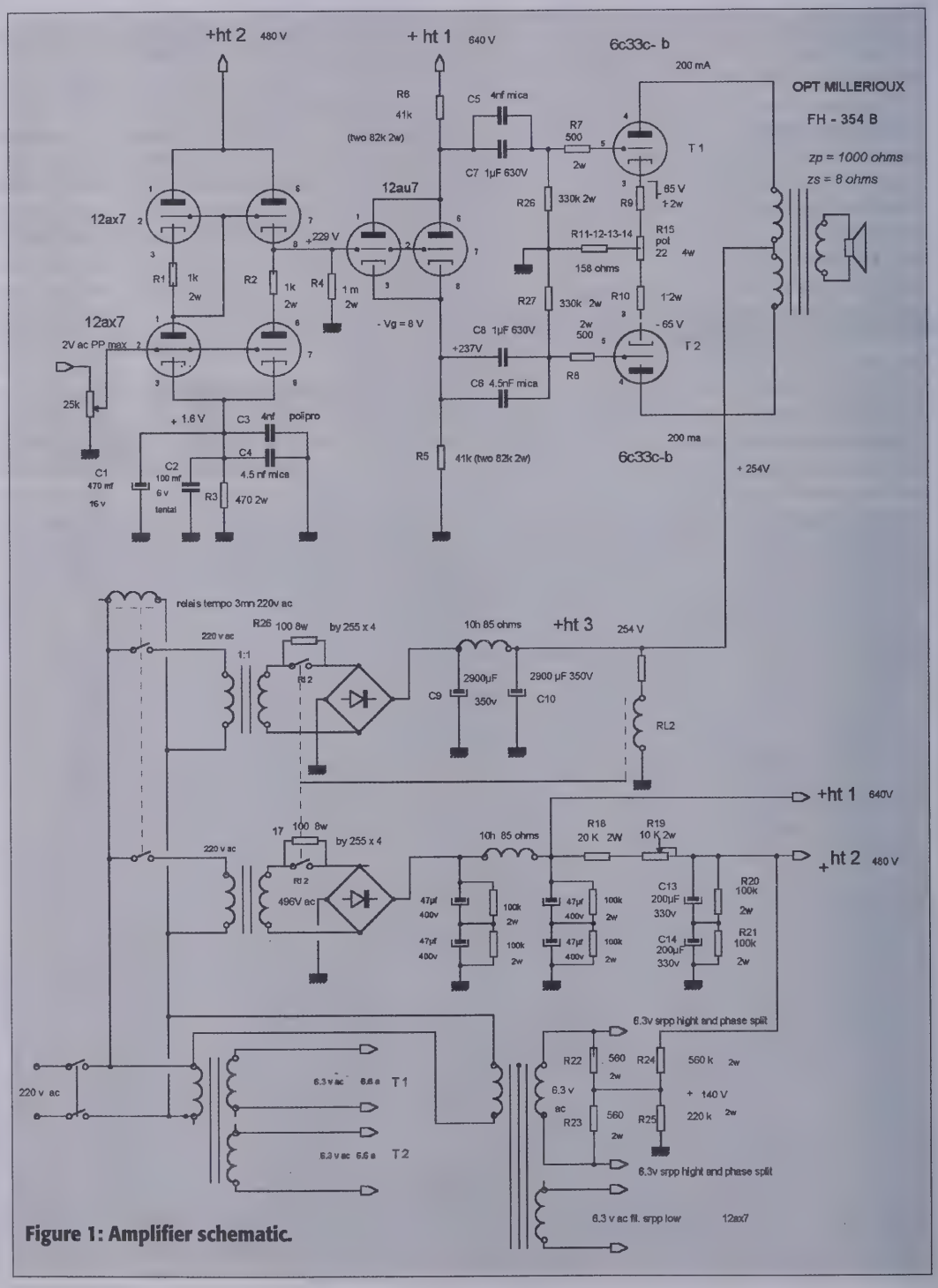

Figure 1: Amplifier schematic.

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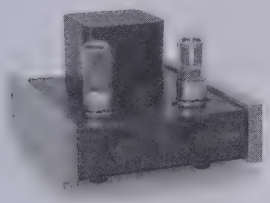

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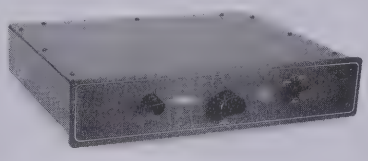

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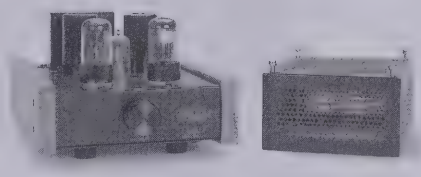

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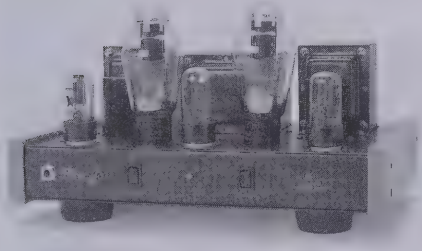

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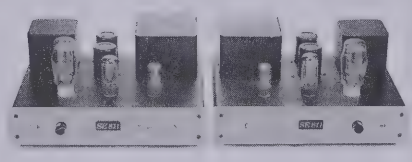

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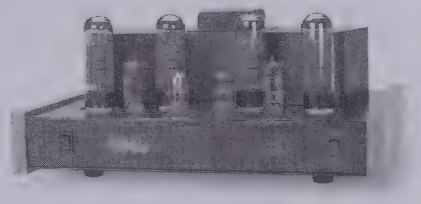

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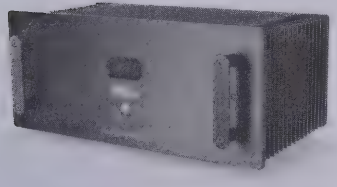

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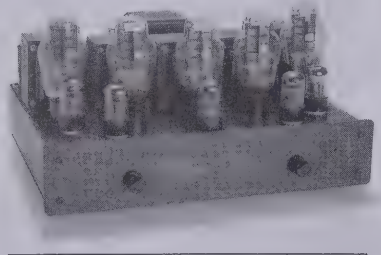

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TABLE 1
AMPLIFIER PARTS LIST

R1, R2	1kΩ metal 2W
R3	470Ω metal 2W
R4	1MΩ metal 2W
R5, R6	41kΩ (two 82kΩ, 2W, paralleled)
R7, R8	500Ω 2W metal
R9, R10	1Ω 2W metal
R11–13	39Ω 50W noninductive
R14	17Ω 25W noninductive
R15	pot 22Ω 4W linear
R16	pot 25k 2W
R17, R26	100Ω 8W
R18	20k 2W
R19	pot 10k 2W
R20, R21	100kΩ 2W
R22, R23	560Ω 2W
R24	560kΩ 2W
R25	220kΩ 2W
R26, R27	330kΩ 2W
C1	470µF 16V electrolytic
C2	100µF 6V tantalum
C3	4nF 100V polypropylene
C4	4.5nF mica 500V
C5, C6	4.5nf mica 500V
C7, C8	1µF 630V MKS
C9–C12	2900µF 350V electrolytic
C13, C14	200µF 330V electrolytic

resistance allows you to obtain the transformer primary more easily, so you have a better speaker damping factor across the transformer. The low frequencies and the transients are of amazing quality. The secret of this stage's operating quality is located there, despite the dispersion of the 6C33C-B's characteristics, an inferior stability, and perhaps an overestimated strength.

It is of the greatest importance that the tubes should be symmetrical, here even more than in any other push-pull, in view of the high anode current. The dispersion of the 6C33C-B characteristics remains significant.

After testing the fixed grid polarization—the 6C33C-Bs not always being perfectly stable—I abandoned that system, which on a material level is much simpler. Instead, I chose cathode polarization with a single resistance, which, as everyone knows, is more effective in controlling the tube output, all the more so since the 6C33C-B may start to output quite suddenly following the least variation of one of the parameters.

The cathode common-resistance polarization system improves the push-pull symmetry with an important distortion-level reduction from 2.5 to 0.5% of odd harmonics with two perfectly matched tubes I chanced to find. At three-quarters power, you can easily observe this with the analyzer spectrum and the distortion meter. The odd harmonics, represented by components in phase, make negative feedback appear, which diminishes the gain of the odd harmonics and consequently reduces the distortion. This common resistance balances the two tubes' symmetry.

I added a 22Ω 4W potentiometer between the two cathodes to reduce the residual asymmetry. This system has the disadvantage that you must set a power resistance inside the amplifier that ought to disperse more than 26W. To see this, I installed four resistors—three of 47Ω 50W, and one of 17Ω 25W—on my model on the exterior of the amplifier's side, mounted on a radiator and ventilated by air circulation. The whole set produces a lot of heat, and you can even use them as temporary heating in winter, but they wouldn't be suitable in a hot Mediterranean summer.

The power stage is connected to the phase splitter with a total capacitance of 1.7µF, composed of several parallel capacitors (polypropylene, polyester, and mica), the circuit's time factor calcu-

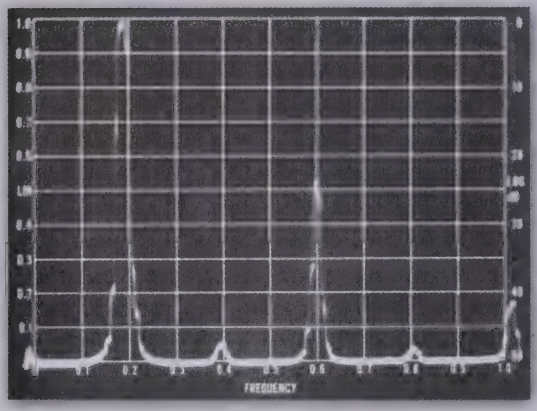

FIGURE 2: Spectrum of 200Hz sine wave, with OPT Millerioux FH354-B; no even harmonics.

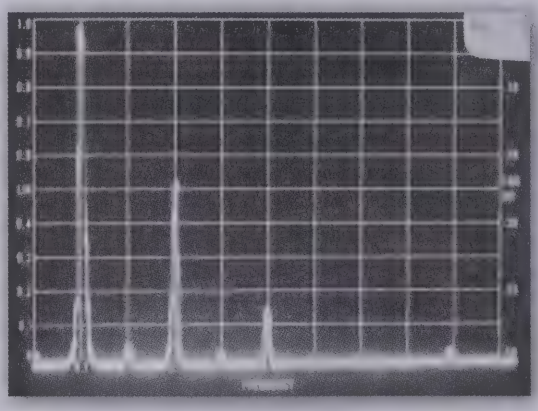

FIGURE 3: Spectrum of 200Hz sine wave with OPT Z70 JBF; DH total 0.5% of odd harmonics; 8W output.

polarize in these conditions. There were instabilities in the anode current, with serious consequences to the milliammeters I had placed in the 6C33C-B cathode circuit. The anode current is 200mA. These tubes require about 20 minutes to heat up and stabilize, and at least an hour to function at their best.

The grid polarization of the phase splitter is about –8V and you can regulate it by adjusting the 10kΩ potentiometer situated on the power-supply circuit.

POWER STAGE

After trying both 6336As with the OPT FH354B on the 1500Ω transformer impedance, I achieved the best low-frequency results with the 6C33C-B by connecting the transformer to the 1000Ω coil. I think this tube with a low internal

Photo 2: Rear view of stereo amp.

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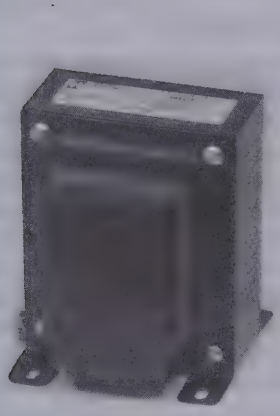

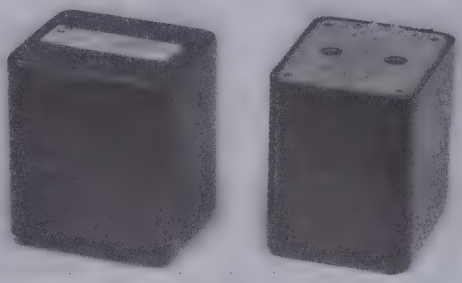

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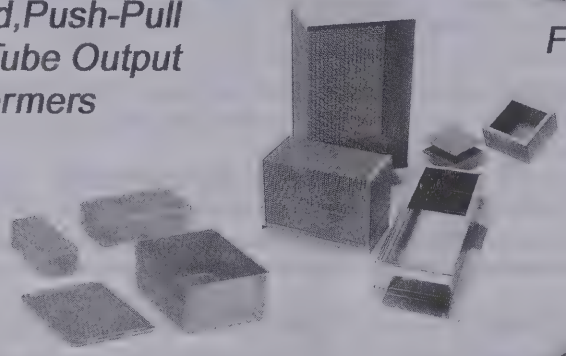

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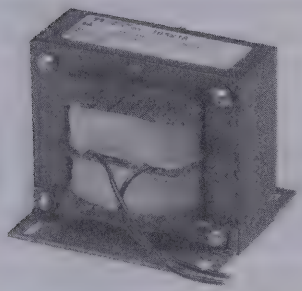

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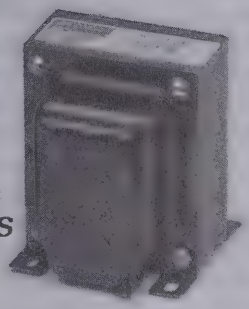

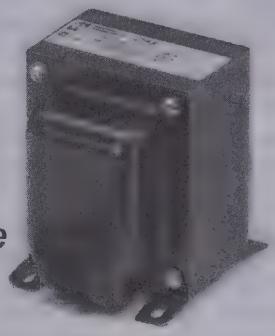

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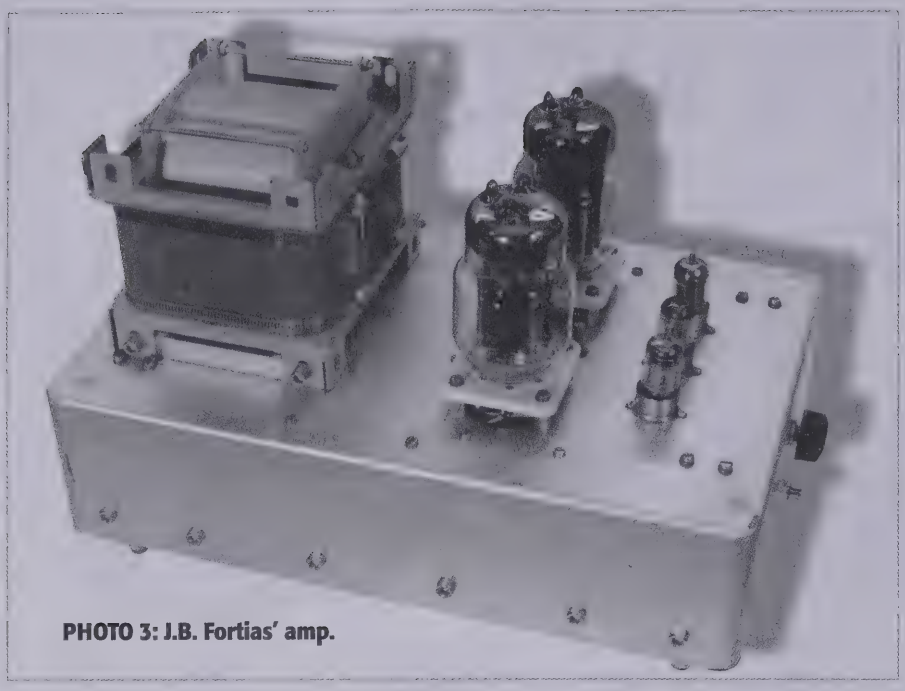

PHOTO 3: J.B. Fortias' amp.

lated according to Brault's method given in his book, *Basse Frequence et Haute Fidelité*, which corresponds to the best passage of the transient and low frequencies.

The 6C33C-B operating point has been set at –65V of the polarization grid, 200mA of the anode current, under 254V HT. Under these conditions, the anode dissipation is 50W per tube. Below this point, even though it was still working under the maximum plate dissipation, I observed that the anodes were slowly becoming red in the dark, so I fixed the polarization grid just below this point, adjusting the cathode resistance to 158Ω.

I adjusted the level at maximum power by applying 2V pk-pk 40Hz AC to the amplifier input, with an 8Ω charge at the output, adjusted the 22Ω potentiometer with a distortion meter for minimum distortion. The two 6C33C-Bs being matched as well as possible, you must try interchanging the tubes to find the minimum distortion level. The cathode current measurement is made at the two 1Ω resistors with a 3V voltmeter that gives the reading directly in mA.

NEGATIVE FEEDBACK

Nevertheless I decided to try a negative-feedback circuit on this amplifier. Then I gave it up, since the circuit wasn't showing any improvement. The distortion level was reduced, the amplifier was losing in dynamic, and the gain of the preamp stage was also insufficient. What you can always improve is the choice of tubes and their matching, which must be as perfect as possible. The quality of the final result depends on it.

OUTPUT TRANSFORMER

Since we were having encouraging results, we decided to build an output transformer more efficient at low and high frequencies than the FH354B Millerioux. After much study, we assembled it in Jean's lab, following the three-wires-in-hand technique. We found the results amazing—a bandpass and distortion curve of 20Hz–40kHz (*Fig. 3*). I made the study for a 10Hz minimal signal frequency, which was set on a Z70 type magnetic circuit. We called it the Z70 JBF (*Photos 3* and *4*), and it weighed 9kgs.

POWER SUPPLY

The power supply is separate for weight and space reasons. Only the 6C33C-B's transformer filament is placed on the amplifier, and the power is provided through high-quality waterproof plugs and cable with gold-plated pins.

The power supply is constructed in classic fashion, with two time-delay relays. The power-level filter electrolytic capacitors are oversized to ensure the power response. 100µF 350V polypropylene capacitors may be mounted in parallel on the electrolytic capacitors to improve the time response of the power supply.

A 140V DC is applied on the low SRPP filaments and on the phase splitter to avoid a filament cathode breakdown at these levels.

CONSTRUCTION DETAILS

To make the heat dispersion easier, I built the first stereo amp on a big frame, 49cm × 30cm × 12cm. A 110V fan supplied with a 1µF capacitor blows slowly and silently, ensuring air circulation through holes on the cathode resistors and the 6C33C-B sockets, but despite that, the heat to be dissipated is still very significant.

SOURCES

OPT FH354B Millerioux is made by [illegible]

OPT Z70 JBF is made by [illegible]

France.

MEASURING INSTRUMENTS:

Spectrum analyzer: Spectrass

Oscilloscopes: Schlumberger, Philips, Hameg, Tectronix.

Distortion meters: L.E.A. ERD 50, EHD 36, Hameg HM 8027

Generators BF: Schlumberger, CRC, Philips, Fensol.

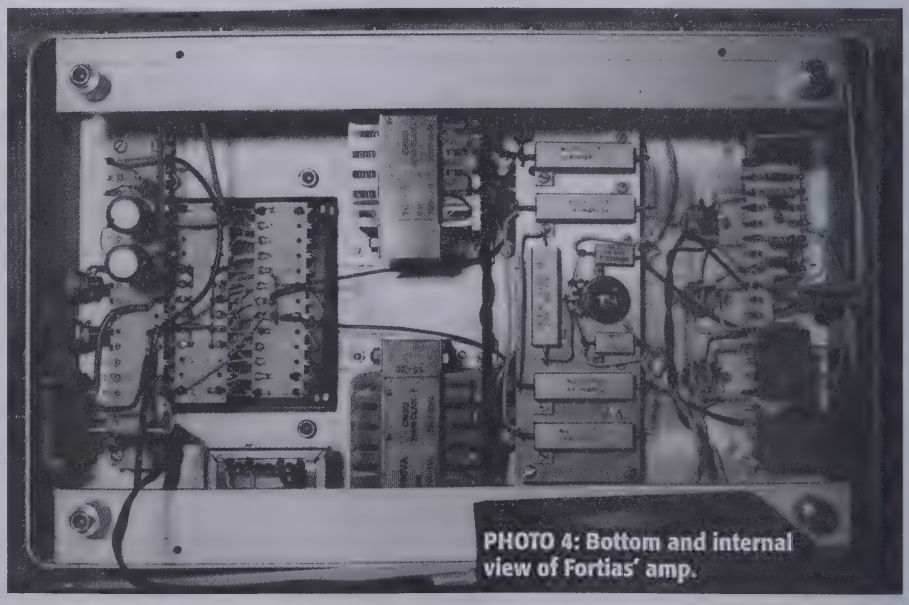

PHOTO 4: Bottom and internal view of Fortias' amp.

Jean built two mono amplifiers with the Z70 JBF output transformer we had perfected. The cathode resistors were placed on a thick aluminum plate in front of the fan, and the 6C33C-B sockets were raised higher.

A more compact power supply is in process, and a circuit that delivers a more powerful signal to obtain a maximum power is now being worked out.

LISTENING RESULTS

Half an hour after you turn on the system, the amplifier stabilizes, and you are immediatly seduced by the dynamic qualities, the tone, the sensation of presence from both sides of the spectrum. The dynamic is amazing, there's no momentary chopping, and the circuits are never overloaded by the transients. The loudspeaker control is just perfect, the sound is absolutely clear, with no confusion whatsoever.

With the Z70 JBF transformer that we built, the bass starts right at the beginning of the audible spectrum. It is natural, well-defined, and of an amazing quality. In the treble, the spectrum frequency is prolonged, with fineness and definition.❖

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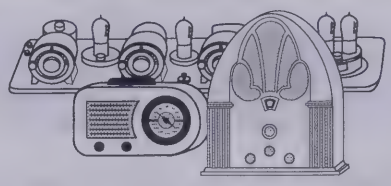

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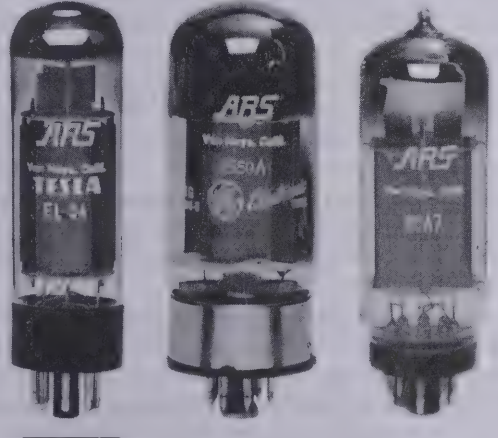

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Reader Service #58

An SV572-10 Push-Pull Amplifier

The author takes you step-by-step through the process of designing (including component selection) and building this push-pull amp based on the SV572 output tube.

BY SCOTT SWARTZ

PHOTO 1: Exterior view of amplifier.

Do-it-yourself audio is a search for the optimum design for your needs, and there are usually many designs tried and discarded before you find the best. Of course, each of these "failures" is a learning process that gives you potentially useful information for the next project. The design I describe in this article (*Photo 1*) originated in exactly this manner.

In the process of trying various concepts on a guitar amp I was building, I noticed that triode-connected pentode power amps are very detailed and have tight well-damped bass, even without feedback. I decided that I didn't like the sound for a guitar amp, but it seemed as though it would work well as a reproduction amplifier.

About a year later, I decided to replace the solid-state power amp I was using in my reproduction system, so, remembering the previous experiments, I began researching triode output stages. A few preliminary experiments showed that the power available from an SE amp was not a good match for my speakers, so I began researching push-pull triode amplifiers. The first step was a definition of my design objectives:

1. Power output of 30W minimum;
2. Low distortion, hum, and noise;
3. Audio signals should pass through a minimum number of stages;
4. No feedback if possible; and
5. Easily obtainable parts.

I could achieve this output power by triode-connected 6550s, but I decided to try directly heated triodes in this design. A desired power output of 30W eliminates the 300B and 2A3 from consideration (assuming only two output tubes). The next step up in power triodes includes the 211 and the Svetlana SV811/572 series. Cost and availability concerns eliminated NOS 211s, and the Chinese versions have a mixed reliability record. Therefore I decided to build my design around the Svetlana SV572, which features directly heated construction, with a massive graphite anode capable of 125W dissipation.

Having settled on the SV572 output tube, the next decision was which mu value of SV572 to use. The data sheets showed the following tube plate-voltage bias: for the SV572-3, 750V, –120V; for the SV572-10, 750V, –40V. (I did not consider the SV572-30 and SV572-160, since they would normally be used with feedback.)

Because the SV572 series requires positive grid drive to achieve good power output, the SV572-3 must have at least 250V pk-pk to achieve the output I desired. For this much drive voltage, I would need an interstage transformer, which I didn't wish to use. Therefore, I selected the SV572-10.

AMPLIFIER DESIGN

Following the usual method of starting at the output stage and working backward, my first step in designing the circuit (*Fig. 1*) was finding a suitable output transformer. The standard rule of thumb for triode output stages is that the primary impedance should be at least twice the plate resistance. Since the Svetlana data sheet stated the plate resistance as 2150Ω, an output transformer for SE operation should be 4–5k, and push-pull twice that, or 8–10k plate-to-plate. Also, the transformer should be rated for at least 100W and be capable of around 100 mA DC per side.

The market isn't exactly crowded with transformers meeting these specs, but Sterling Audio has a good match that was designed for use with the 211. Other options were the Antique Electronic Supply OPT-116 or a custom-made unit from EA Sowter or Audio Transformers. The Sterling Audio 211 specifications are: primary impedance, 9.5kΩ; power output, 150W; and standing DC current, 100mA.

These specs closely match the requirements. If the allowable DC current were higher, you could operate the SV572s at higher dissipation for better linearity (theoretically), but measurements of the finished amplifier show linearity is not a problem. The SV572-10s operate at 750V on the plates and 100mA current, for a dissipation of 75W. This is conservative for this tube, since it is capable of 125W.

A direct-coupled 6BL7 cathode follower drives the grids of the SV572-10s. I tried capacitor coupling on an earlier version, but could achieve only about 10W before extreme crossover distortion. Perhaps a lower-impedance cathode follower such as the low-mu section of a 6EA7 would deliver more positive drive. This would be similar to the circuit in Eric Barbour's article, "Improving the SE SV811-10 Amplifier" (*GA* 5/97, p. 12). In any case, I decided to accept the power-supply complications and went with the direct coupling.

The bias on the SV572s is set by ad-

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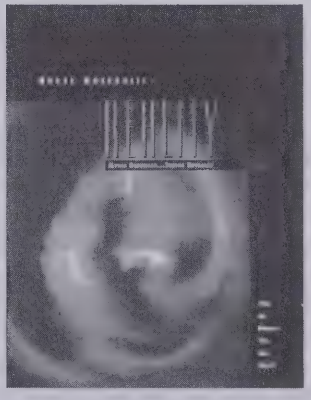

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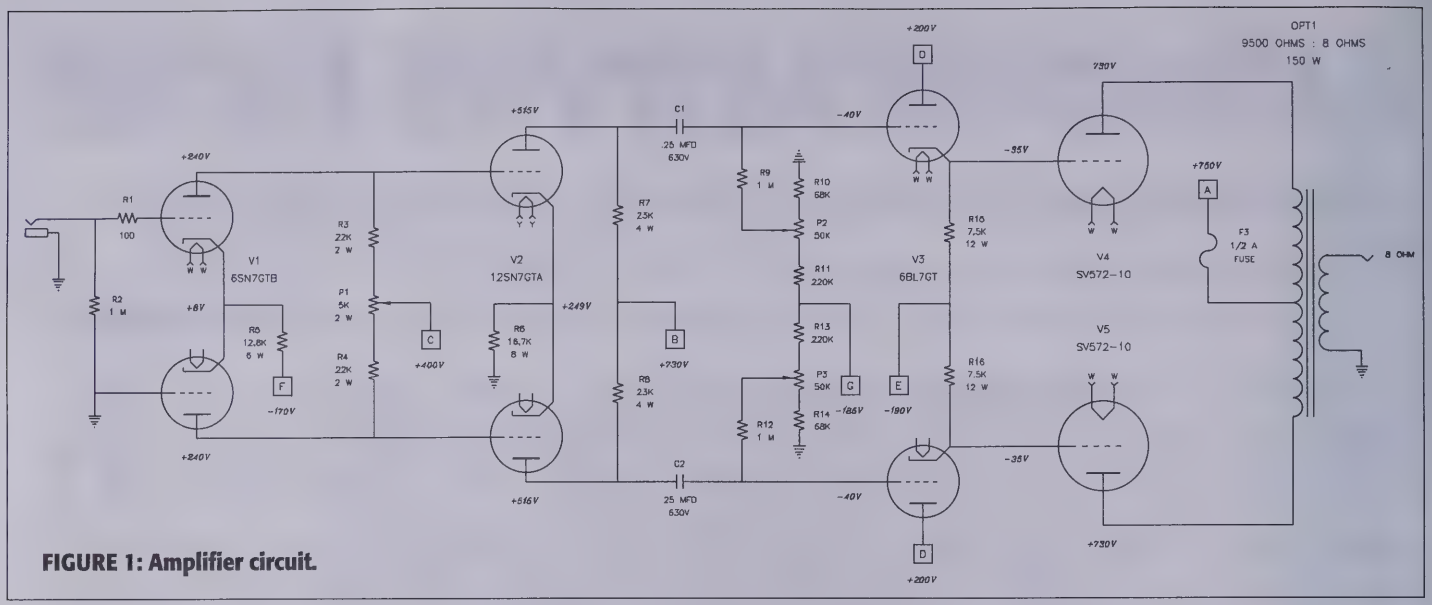

FIGURE 1: Amplifier circuit.

justing the grid bias of the 6BL7. This in turn varies the current through the 6BL7 and changes the voltage drop across its cathode resistor, which alters the voltage present on the cathode. You can use this system only for small bias adjustments, because the current flow through the 6BL7 becomes important when the SV572-10 grids are driven positive. This makes the value of the cathode resistor significant, so proper current and bias range are achieved simultaneously.

I selected a cascaded differential amplifier driver section because it provides low distortion, cancels hum, and is amenable to direct coupling between stages. This design is well proven; many examples have appeared in the literature. It uses a negative supply as a passive current source on the input differential amplifier, thus allowing the desired bias on the stage. The input stage is direct-coupled to the driver differential amplifier. This places the driver differential amplifier's cathode at +250V, which is returned to ground through a passive current source (a high-value resistor). The output of the driver differential amplifier is RC-coupled to the cathode followers. I selected the 12SN7GTA for this stage because of its low distortion and high output-voltage capability.

I have selected the tube for the driver differential amplifier, but the tube for the input differential amplifier will be determined by the desired input sensitivity. I knew I wished to drive the amplifier with line-level input (approximately 1V pk-pk) and to drive the SV572-10 grids to +15V. The required voltage swing is 2 × (35 + 15) = 100V pk-pk, so I needed a voltage gain of about 100.

An SN7 differential amplifier provides a gain of approximately 10, so two SN7 stages cascaded would provide the desired gain of 100. Therefore I selected an SN7 for the input differential amplifier (I used a 6SN7GTB in this location because of a filament-bias issue). The driver could provide more than 100V pk-pk, but the cathode follower driving the SV572-10 could not deliver the current to drive the grid more positive. I could obtain more output power with a lower-impedance driver, but the power with this design was ample for my needs.

POWER SUPPLY

This project is typical for tube amplifiers in that the power supply (*Figs. 2* and *3*) is more work than the amplifier circuit. The direct coupling used between the differential amplifiers and the cathode follower and power tube necessitates regulated supplies to provide the various voltage levels. The regulated supplies also make hum a nonissue and stabilize the bias on the output stage.

The positive supply voltages this design requires are summarized in *Table 1*. The power transformer supplies both a pi filter and a choke filter, and these raw voltages are adjusted to the desired values using vacuum-tube regulators. A negative voltage is supplied by a second power transformer that feeds a pi filter and a vacuum-tube regulator.

HAMMOND 720 TRANSFORMER

The various positive voltages required are supplied by a Hammond 720 transformer rated 625V-0V-625V at 300mA CCS or 450mA ICAS (115V AC supply). Both the pi-filter and choke-input-filter sections use solid-state rectifiers with balancing resistors and small capacitors to help absorb voltage spikes. The pi-filter section, which supplies the SV572s, gives about 920V DC no load and around 820V DC at the design current.

A regulator using a 6080 pass tube and a 12AU6 error amplifier provides 750V DC to the SV572s. Zener diodes function as the error-amplifier cathode-voltage reference, and also regulate the screen voltage. This regulator's design is similar to Douglas McCann's purist tube regulator described in great detail in *GA* 3/94. See also "Vacuum Tube Regulator Design," by Denzil Danner in *GA* 3/93. It uses only one 6080 because of the low plate voltage in this design and because the current draw is relatively constant, since all amplifier stages are Class A differential. An RC filter connected to the +750V DC provides the +720V DC to the driver differential amplifier.

If the output stage were operated Class AB2 with a higher plate voltage, as shown in Svetlana's data on the SV572-10, two 6080s would be required to provide more headroom for the current peaks. This would, of course, require a different power transformer and some other changes, although the output power would rise to 150W.

The Hammond 720 also has a choke-input filter that supplies raw voltage for the +400V DC and +200V DC regulators. This filter also lowers the plate voltage on the +400V DC regulator, which uses a 15EA7 tube having a low-mu section serving as the pass element, and a high-mu section that serves as the error amplifier. A zener diode is used as the voltage reference.

This 400V regulator is similar to the one shown in Bruce Rozenblit's "Transformerless Output Amplifier" (*GA* 2/90).

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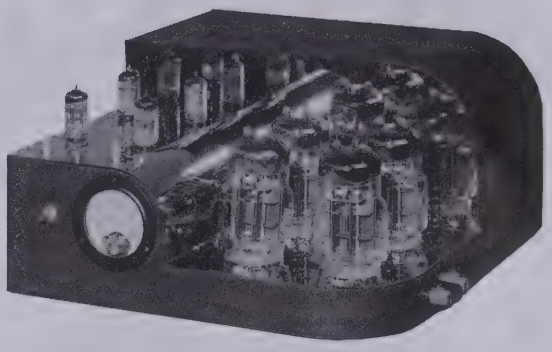

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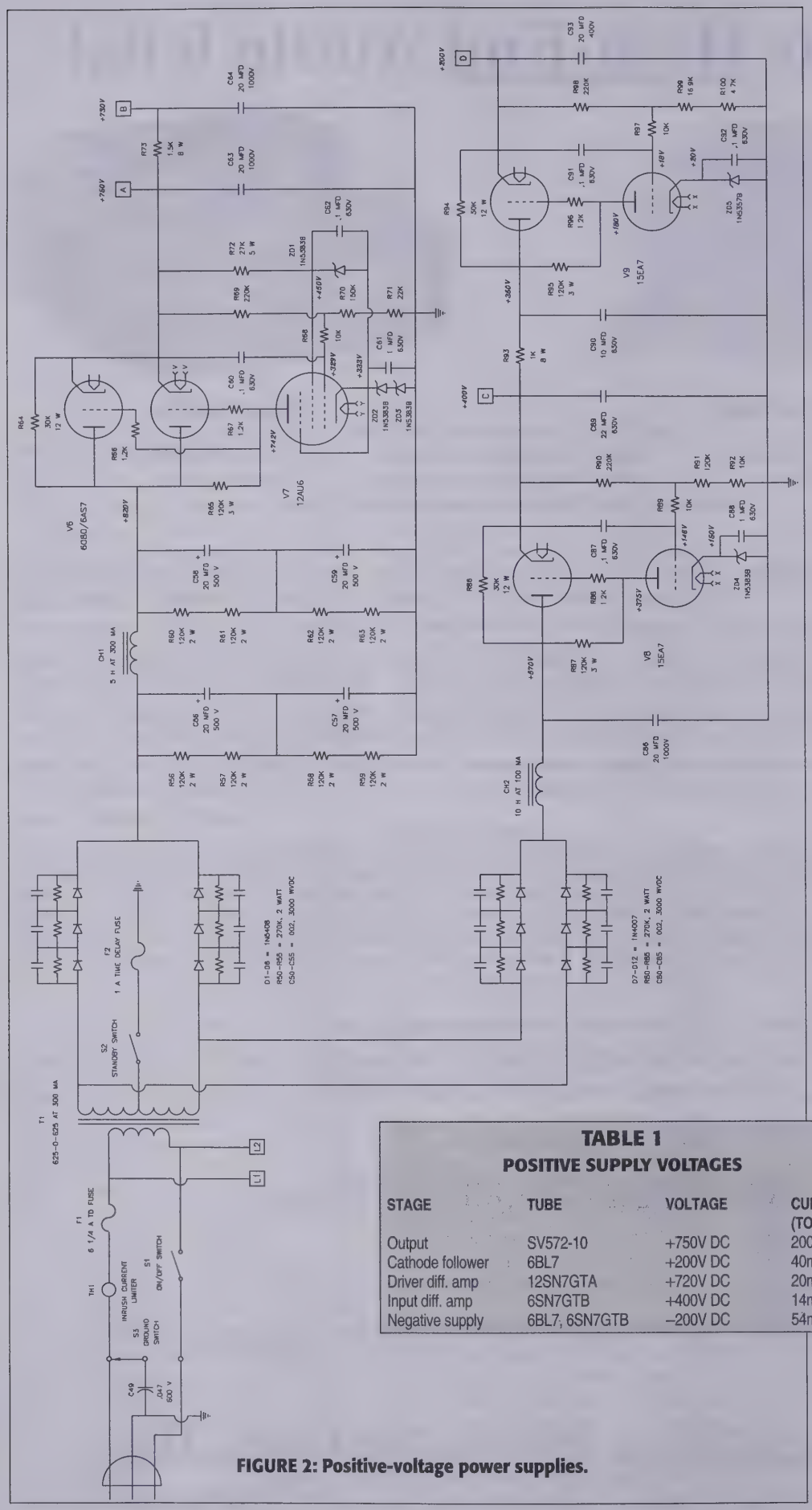

FIGURE 2: Positive-voltage power supplies.

It supplies the input differential amplifier as well as the +200V DC regulator, which has the same circuit as the +400V DC regulator, with slight changes in some component values.

THE HAMMOND 269GX

The Hammond 269GX power transformer, rated 225V-0V-225V at 65mA, supplies solid-state rectifiers and a pi filter that provides raw voltage for the –200V DC regulator. The pi filter gives about –300V DC at the design current. This regulator also uses a 15EA7 and has the same circuit as the +400V DC and +200V DC regulators.

All filter capacitors beyond the regulators are metallized polypropylene. Electrolytics are used in the high-voltage raw supply to save space, and the capacitors are modestly sized to provide good transient response. The filter capacitors for the +750V DC and +720V DC may be somewhat hard to find because you need at least a 1kV rating. I used a 2 × 10µF 1kWV DC metallized polypropylene capacitor from a surplus store.

Similar to the design on many guitar amplifiers, on/off and standby switches control the amplifier. To power it up, you move the on/off switch to the on position; after 30 seconds, you turn the standby switch to "on," thereby applying the B+ and B– to the amplifier circuit. (You could automate this process with relays.)

You should never apply the B+ until the filaments are warmed up, since this causes cathode stripping, resulting in shortened tube life. It can also cause the pass tube of a vacuum-tube regulator to arc and destroy itself, which I experienced during construction.

I worked around this problem by adding a resistor connected between the plate and cathode of the pass tubes, thus providing a bypass for the current while the tube warms up. The arcing occurs because of the close spacing of the plate, grid, and cath-

TABLE 1
POSITIVE SUPPLY VOLTAGES

STAGE	TUBE	VOLTAGE	CURRENT (TOTAL)
Output	SV572-10	+750V DC	200mA
Cathode follower	6BL7	+200V DC	40mA
Driver diff. amp	12SN7GTA	+720V DC	20mA
Input diff. amp	6SN7GTB	+400V DC	14mA
Negative supply	6BL7, 6SN7GTB	–200V DC	54mA

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Nominal Power, RMS (note 1)	40	70	100	80 Triode	70	100	70	100	100	70	Watt
Primary Impedance (Raa)	5878	2756	1885	1239	4000	2000	4000	2000	2000	4000	ohm
Primary Current (IDC), maximum	117	225	326	359	258	387	258	387	315	387	mA
Sec. Load Impedance, nom. (Rls)	5	5	5	5	4	4	5	5	5	5	ohm
Turns Ratio (Np:Ns)	34.28:1	23.48:1	19.42:1	15.74:1	31.6:1	22.4:1	28.3:1	20.0:1	20.0:1	28.3:1	
Ultra Linear Tap	40	40	40	40	40	40	33	33	33	-100	%
Cathode Feed-back Tap	-	-	-	-	-	-	7.1	10	10	100	%
Frequency Range, Flat (note 3)	24	63.7	96.5	104.5	84	102	67	84	131	110	kHz
Frequency Range, -1dB (note 3)	53.5	120.6	152.2	173	131	134	136	149	204	244	kHz
Frequency Range, -3dB (note 3)	98.8	187.4	217	251.5	185	177	222	224	290	451	kHz
Power Bandwidth Start, -3dB	25	22.7	20.7	20.5	14	14	14	14	23	14	Hz
Total Pri. Inductance (Lp) (note 2)	535	490	530	360	1163	675	1056	663	505	1574	H
Leakage Inductance, Pri to Sec (Lsp)	3.7	2.6	1.8	1.312	3.2	2.1	3.1	1.4	1.5	0.67	mH
Effective Primary Capacitance (Cip)	613	558	585	593	345	660	358	638	400	388	pF
Total Primary Resistance (Rip)	68.1	173.7	104	37.8	114	57	120	63	56	78.4	ohm
Total Secondary Resistance (Ris)	0.158	0.168	0.18	0.16	0.10	0.13	0.15	0.17	0.10	0.18	ohm
Insertion Loss (Ilos)	0.18	0.4	0.38	0.26	0.23	0.26	0.25	0.28	0.2	0.24	dB
Quality Factor (Lp/Lsp)	144,610	188,510	294,410	274,410	366,000	321000	338,000	474,000	337,000	2,440,000	
Freq. Decade Factor (FDF) (note 4)	5.07	5.67	5.85	5.96	5.7	5.47	6.03	5.96	5.95	6.7	
Case size, diameter x height	Black Polyamid 125.6 x 65.3				Spun Aluminum, with textured black finish 152.4 x 88.9						mm
Weight	2.4	2.4	2.6	2.6	5.43	6.18	5.62	6.21	4.42	5.53	kg
Price $US	$201	$205	$201	$185	$302	$271	$283	$247	$249	$260	$US
Price $CN	$251	$257	$251	$231	$378	$339	$354	$309	$311	$325	$CN

Notes: 1) Measured and calculated with balanced DC current and AC anode voltage in the circuit power tubes. 2) 240V 60Hz across primary winding.
3) Measured and calculated at 1mW in Rls; ri and Rls are resistive loads. 4) FDF=log (fh3/fl3) = number of frequency decades transferred.

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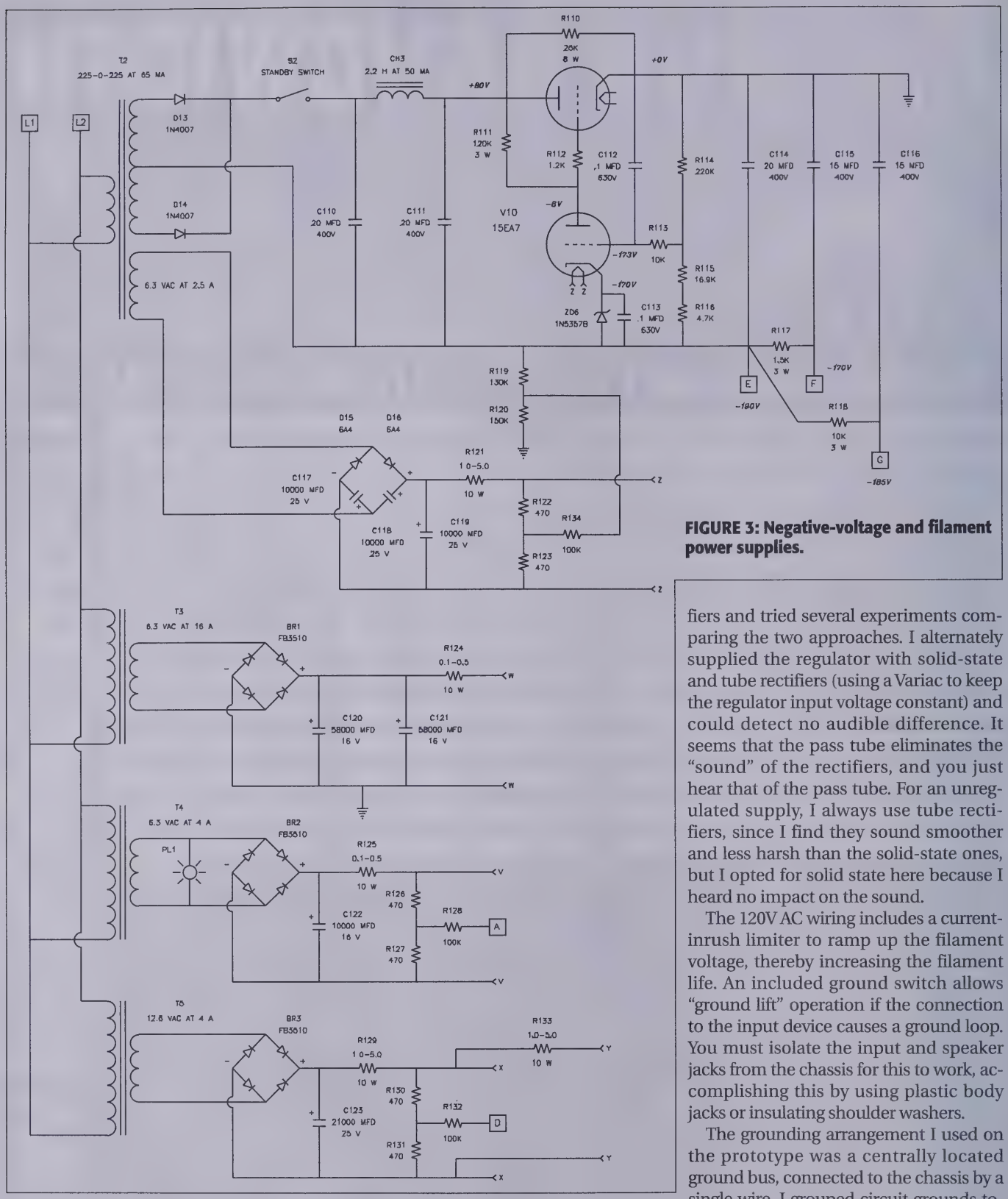

FIGURE 3: Negative-voltage and filament power supplies.

ode that's inherent in a high-perveance tube (one capable of high current flow at low plate voltage). The resistors prevent destruction of the tubes if you forget to use the standby switch, but they don't stop the cathode stripping.

Using tube rectifiers would eliminate this problem, but would require a higher-voltage power transformer, additional filament transformers, and so on. Also, the tube rectifier would need a PIV specification of at least 2kV and would preferably be indirectly heated. This is a good application for a pair of TV damper diodes, such as the 6AU4GT.

I considered changing to tube rectifiers and tried several experiments comparing the two approaches. I alternately supplied the regulator with solid-state and tube rectifiers (using a Variac to keep the regulator input voltage constant) and could detect no audible difference. It seems that the pass tube eliminates the "sound" of the rectifiers, and you just hear that of the pass tube. For an unregulated supply, I always use tube rectifiers, since I find they sound smoother and less harsh than the solid-state ones, but I opted for solid state here because I heard no impact on the sound.

The 120V AC wiring includes a current-inrush limiter to ramp up the filament voltage, thereby increasing the filament life. An included ground switch allows "ground lift" operation if the connection to the input device causes a ground loop. You must isolate the input and speaker jacks from the chassis for this to work, accomplishing this by using plastic body jacks or insulating shoulder washers.

The grounding arrangement I used on the prototype was a centrally located ground bus, connected to the chassis by a single wire. I grouped circuit grounds together by stage, and ran the groups back to the bus with a single wire. This technique seems to work as well as true star grounding, and is easier to implement.

FILAMENTS

You could build this amplifier entirely with 6V heater tubes, but there are many

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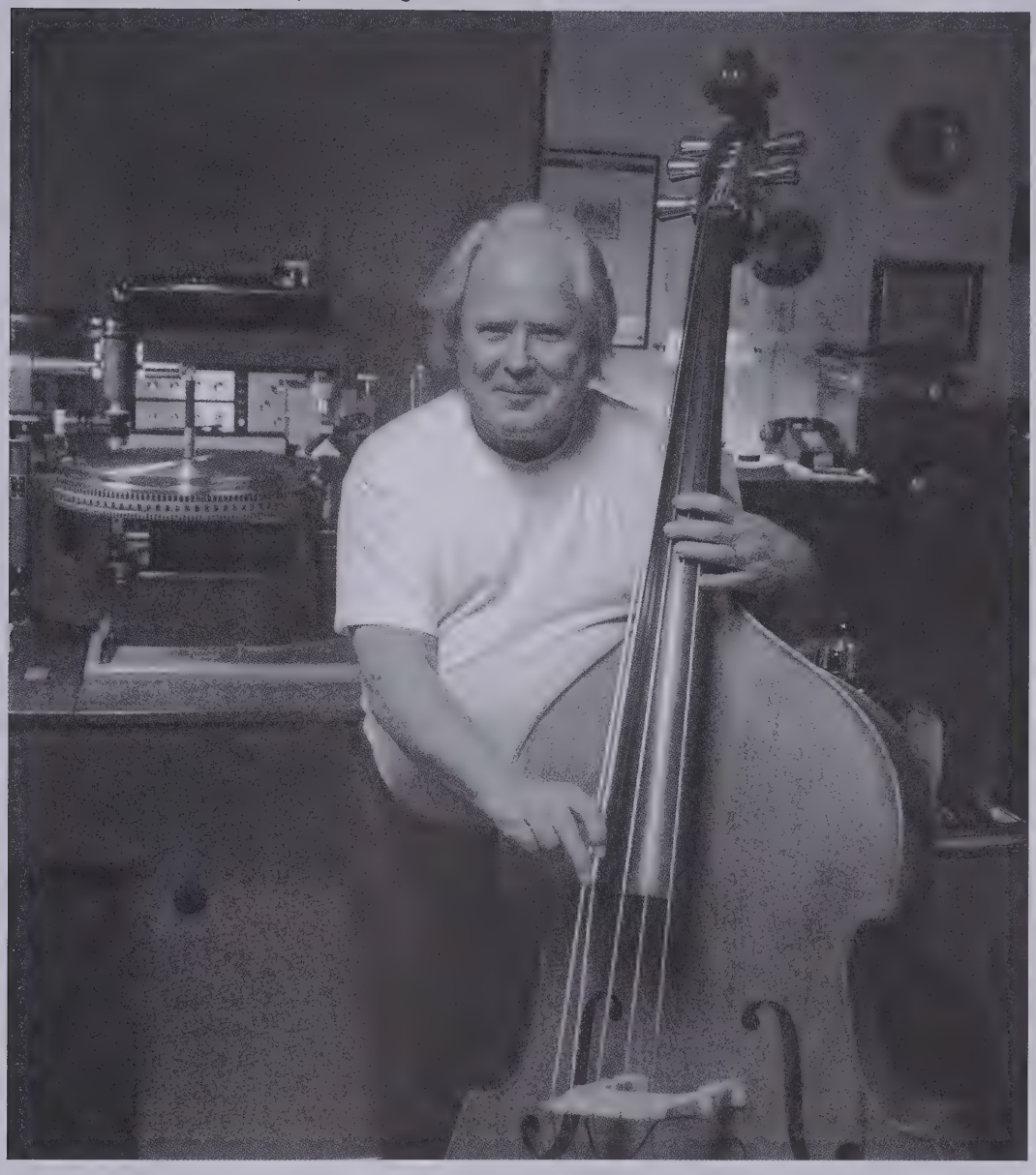

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possible ways to achieve the same combination of desired stage characteristics. Tubes with nonstandard filament voltages are often much cheaper, and since this design requires multiple filament transformers to achieve the different bias levels, it is an ideal opportunity to use these "oddball" tubes.

For instance, you could replace 6EA7s with 15EA7s, or 6SN7s with 12SN7s. I chose to do this on my prototype to save money on tubes, both now and in the future. A 6EA7 currently costs $6–7; I recently purchased 15EA7s for $0.50 each on sale. I recommend making a chart showing each tube and the bias and current required (see *Table 2*). Then you can group the tubes to provide efficient use of the filament transformers.

TABLE 2
SAMPLE TUBE-REQUIREMENTS CHART

TUBE	FILAMENT VOLTAGE	FILAMENT CURRENT	CATHODE VOLTAGE	FILAMENT BIAS	FILAMENT TRANSFORMER
SV572-10 (2)	6.3V	8.0A	+6V	0V	T3
6BL7GT	6.3V	1.5A	-40V	0V	T3
6SN7GTB	6.3V	0.6A	+8V	0V	T3
6080	6.3V	2.5A	+750V	750V	T4
12SN7GTA	12.6V	0.3A	+250V	200V	T5
15EA7	14.8V	0.45A	+400V/+150V	200V	T5
15EA7	14.8V	0.45A	+200V/+20V	200V	T5
12AU6	12.6V	0.15A	+300V	200V	T5
15EA7	14.8V	0.45A	0V/–200V	–100V	T2

The largest heater-cathode voltage potential is 200V DC on one of the 15EA7s. This is higher than the maximum DC potential given in tube manuals, but values

TABLE 3
PARTS LIST

CAPACITORS	VALUE (µF)	WV DC	TYPE	MANUFACTURER	SUPPLIER[2]
C1, C2,	0.25	630V	polypropylene film/foil	SBE	AI, AES
C49	0.047	630V	metallized polypropylene	XICON	MSR
C50–55, C80–85	0.002	3000V	ceramic	SBE	NEW
C56–59	20	500V	electrolytic	SBE	AI
C60–62, C87, C88, C91, C92, C112, C113	0.1	630V	metallized polypropylene	XICON	MSR
C63, C64, C86	2 × 10	1000V	metallized polypropylene	ASC	GTW
C89	22	630V	metallized polypropylene	Solen	AI
C90	10	630V	metallized polypropylene	Solen	AI
C93, C110, C111, C114	20	400V	metallized polypropylene	Solen	AI
C115, C116	15	400V	metallized polypropylene	Solen	AI
C117–119	10,000	25V	electrolytic	XICON	MSR
C120, C121	58,000	16V	electrolytic	Cornell Dubilier	NEW
C122	10,000	16V	electrolytic	XICON	MSR
C123	21,000	25V	electrolytic	Cornell Dubilier	NEW
ITEM	**PART NUMBER**	**DESCRIPTION**	**MANUFACTURER**	**SUPPLIER[1,2]**	
D1–6	1N5408	diode, 3A, 1000 PIV	Fagor, IR, Motorola	NEW, MSR	
D7–14	1N4007	diode, 1A, 1000 PIV	Fagor, IR, Motorola	NEW, MSR	
D15, D16	6A4	diode, 6A, 400 PIV	Rectron	MSR	
ZD1–4	1N5383B	zener diode, 5W, Vz = 150V	Fagor, Motorola	NEW	
ZD5, ZD6	IN5357B	zener diode, 5W, Vz = 20V	Fagor, Motorola	NEW	
BR1–3	FB3510	bridge rectifier, 35A, 1000 PIV	Fagor, IR	NEW, MSR	
V1	6SN7GTB	twin triode	as desired		
V2	12SN7GTA	twin triode	as desired		
V3	6BL7GT	twin triode	as desired		
V4, V5	SV572-10	power triode	Svetlana	Svetlana	
V6	6080	twin triode	as desired		
V7	12AU6	pentode	as desired		
V8–10	15EA7	dual triode	as desired		
PL1	N/A	6V pilot light	as desired	as desired	
S1	N/A	switch, SPST, rated 10A @ 250V AC	as desired	as desired	
S2	N/A	switch, DPDT, rated 10A @ 250V AC	as desired	as desired	
S3	N/A	switch, SPDT, rated 10A @ 250V AC	as desired	as desired	
TH1	CL101	inrush current limiter, 16A	Keystone	MSR	
F1	MDL-6¼	fuse, 6¼ A time delay	Bussman	MSR, NEW	
F2	MDL-1	fuse, 1A time delay	Bussman	MSR, NEW	
F3	AGC-½	fuse, ½A fast blow	Bussman	MSR, NEW	
P1	RV-5K	5k linear, 2W potentiometer	Ohmite	ALL	
P2, P3	N/A	50k linear 2W potentiometer	as desired	SURPLUS	
RESISTORS	**VALUE**	**WATTAGE**	**TYPE**	**SUPPLIER[2]**	
R50–55, R80–85	270k	2W	Metal oxide (MO)	MSR	
R56–63	120k	2W	MO	MSR	
R64, R86, R94	30k	12W	Wirewound (WW)	NEW	
R65, R87, R95, R111	120k	3W	MO	MSR	
R66, R67, R88, R96, R112	1.2k	½W	Metal film (MF)	MSR	
R68, R89, R92, R97, R113	10k	½W	MF	MSR	

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Table 3 continued

R69	220k	2W	MO	MSR	
R70	150k	2W	MO	MSR	
R71	22k	½W	MF	MSR	
R72	27k	5W	WW	NEW	
R73	1.5k	8W	WW	NEW	
R90, R98, R114	220k	1W	Carbon film (CF)	MSR	
R91	120k	1W	CF	MSR	
R93	1k	8W	WW	NEW	
R99, R115	16.9k	½W	MF	MSR	
R100, R116	4.7k	½W	MF	MSR	
R110	25k	8W	WW	NEW	
R117	1.5k	3W	WW	NEW	
R118	10k	3W	WW	NEW	
R119	130k	2W	MO	MSR	
R120	150k	2W	MO	MSR	
R121, R129, R133	1.0–5.0	10W	WW	NEW	
R122, R123, R126, R127, R130, R131	470	½W	MF	MSR	
R124, R125	0.1–0.5	10W	WW	NEW	
R128, R132, R134	100k	1W	CF	MSR	

RESISTORS	VALUE	WATTAGE	TYPE	NOTES	SUPPLIER[2]
R1	100	1W	Carbon composition (CC)		Surplus
R2, R9, R12	1m	1W	CC		Surplus
R3, R4	22k	2W	CC		Surplus
R5 Surplus	12.8k	6W	CC	39k, 39k, 39k in parallel	
R6 Surplus	16.7k	8W	CC	68k, 68k, 68k, 56k in parallel	
R7, R8	23k	4W	CC	56k, 56k in parallel	Surplus
R10, R14	68k	1W	CC		Surplus
R11, R13	220k	1W	CC		Surplus
R15, R16	7.5k	12W	WW		NEW

ITEM	PART NUMBER	MANUFACTURER	DESCRIPTION	SUPPLIER[2]
T1	720	Hammond	Power trans, 625V-0V-625V @ 300mA	AES, AI
T2	269GX	Hammond	Power trans, 225V-0V-225V @ 65mA, 6.3V @ 2.5A	AES, AI
T3	167U6	Hammond	Filament trans, 6.3V @ 16A	AES, AI
T4	167N6	Hammond	Filament trans, 6.3V @ 4A	AES, AI
T5	167N12	Hammond	Filament trans, 12.6V @ 4A	AES, AI
CH1	193L	Hammond	Choke, 5H @ 300mA	AES, AI
CH2	158M	Hammond	Choke, 10H @ 100mA	AES, AI
CH3	153H	Hammond	Choke, 2.2H @ 50mA	AES, AI
OPT1	211	Sterling Audio	Output trans, 150W, 9500Ω: 8Ω	Sterling

NOTES

1. See text for vacuum-tube suppliers.
2. Key to supplier abbreviations:

AES	Antique Electronic Supply
AI	Angela Instruments
ALL	All Electronics
GTW	Gateway Electronics
MSR	Mouser Electronics
NEW	Newark Electronics

given for this parameter are typically very conservative. If this worries you, the loads for transformer T5 could be served by two filament transformers, one with a bias of +100V DC and the other with a bias of +275.

All filament supplies are DC, using a bridge rectifier, a filter cap sized for approximately 10,000µF per filament amp, and a dropping resistor. I find that adding these few components is a small price to pay for eliminating all concerns about filament-related hum. All filament transformers are sized at no more than 70% of their rated current to allow for the current peaks caused by the rectification to DC.

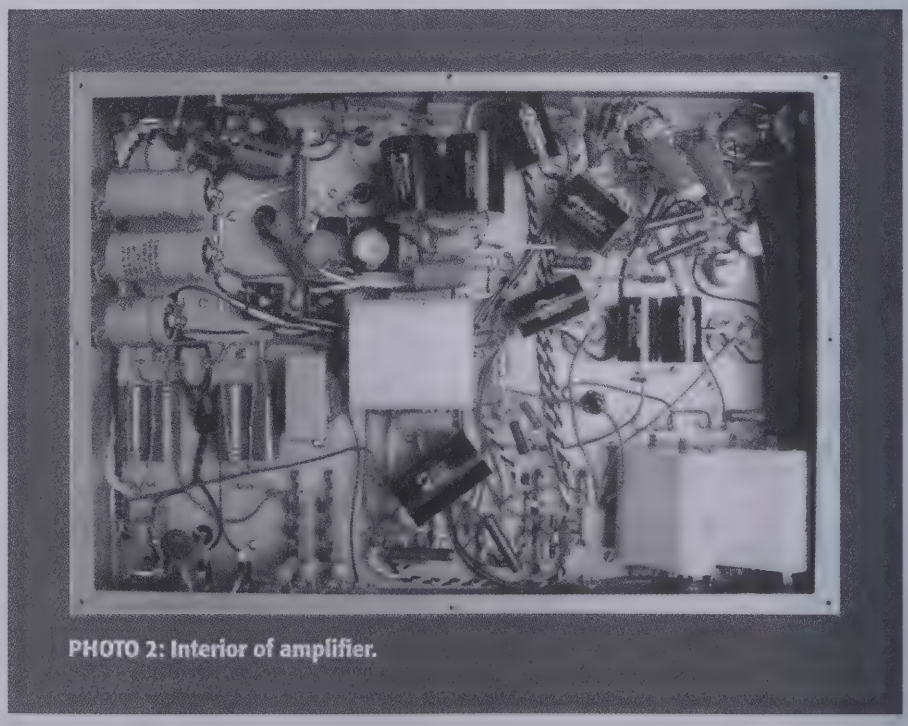

PHOTO 2: Interior of amplifier.

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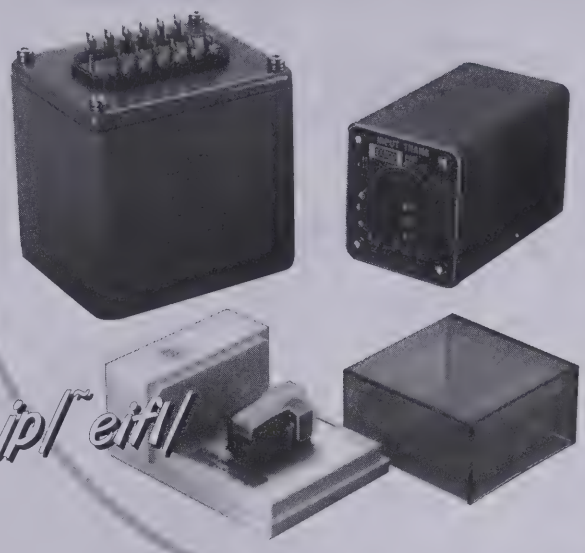

■Cartridge

Model	Price (US $)	Postage (Air Economy)
Denon DL-102 (MONO)	150	Area I $18: China, Korea, Hong Kong, Taiwan
Denon DL-103 (STEREO)	160	Area II $22: Singapore, Malaysia, Indonesia
Denon DL-103R (STEREO)	250	Area III $27: North America, Oceania, Europe
Shelter Model 501 II (Crown Jewel)	650	Area IV $34: Africa, South America
Ortofon SPU Classic GE	630	

These Area I ~ IV are for all products except book.

■Japanease Audio Book

Title	Price (US $)	Postage* (Air Economy)
Attractive Tube Amps Vol. 1&2 (Isamu Asano)	30 each	Area I $10: Asia
Joy of Vintage Tube Amps (Tadaatsu Atarashi)	28	Area II $9: North America, Europe, Oceania
JBL Moniter Speakers (Stereo Sound)	23	Area III $8: Africa, South America
MJ Selected 300B Amps	21	
Audio Tubes(Hisashi Ohtsuka)	35	
SE Amps by Transmitting Tubes (Kouichi Shishido)	50	

* These Area I, II, III are for book only.

■Speaker

Model	Specifications					Price*	Postage** (US $)			
	D(cm)	Ω	Response	db	w	(US $)	I	II	III	IV
Fostex FE208 Σ	20	8	45Hz~20kHz	96.5	100	296	62	74	120	156
Fostex FE168 Σ	16	8	60Hz~20kHz	94	80	236	42	50	73	98
Fostex FE108 Σ	10	8	80Hz~18kHz	92	15	144	30	36	50	66
Onken OS5000T	—	8	7kHz~25kHz	105	2.5	2,800	70	84	133	181
STAX SR-001	S-001 Ear Speaker+SRM-001 Drives Unit					248	24	29	39	50

*Price is for a pair except SR-001. **Air Economy

■Tonearm

Model	Specifications	Price (US $)	Postage* (US $)			
			I	II	III	IV
Ikeda IT345	・Dynamic Balanced Type ・Length IT345 245mm IT407 307mm ・Stylus Pressure 0~5g	1600	24	29	39	50
Ikeda IT407		1800	30	36	50	66

*Air Economy

■Transformer

Model (SE OPT)	Specifications				Price*	Postage** (US $)			
	W	Pri.Imp(kΩ)	Freq Response	Application	(US $)	I	II	III	IV
Tango XE-60-5SNF	30	5	25Hz~70kHz	300B, 50, PX-25	612	62	74	115	156
Tango XE-20S	20	2.5, 3.5, 5	20Hz~90kHz	300B, 50, 2A3	384	47	56	84	113
Tango FW-150-10SR	40	10	25Hz~35kHz	211, VT-4C	940	76	92	147	201
Tango NY-15-3.5S (45% Permalloy)	15	3.5	20Hz~45kHz	300B, 50 2A3	876	62	74	115	156
Tango U-808	25	2, 2.5, 3.5, 5	20Hz~65kHz	6L6, 50, 2A3	238	42	50	73	98
Tango X-5S	40	5	18Hz~70kHz	50, 845	1074	79	96	154	211
Tamura F-7001 (Permalloy)	8	3	15Hz~60kHz	300B,2A3	650	42	50	73	98
Tamura F-7003 (Permalloy)	10	5	15Hz~50kHz	300B,50	760	42	50	73	98
Tamura F-2013	40	10	20Hz~50kHz	211,VT-4C	730	57	68	105	142

*Price is for a pair. ** Air Economy

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Reader Service #78

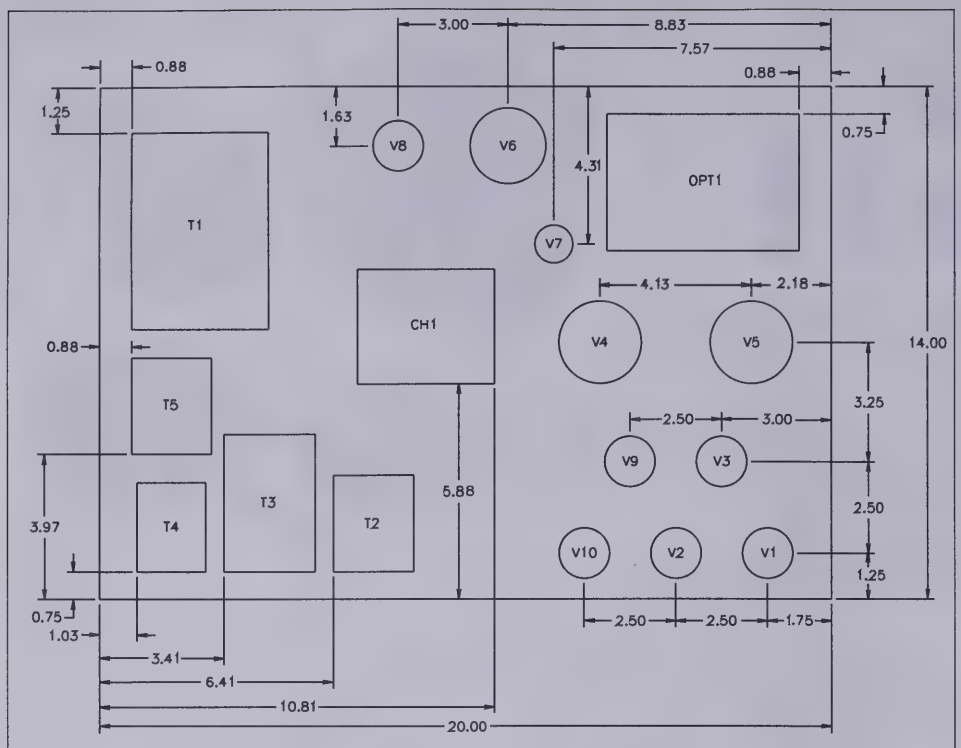

FIGURE 4: Chassis exterior (top view).

Transformer T3, rated 6.3V AC at 16A, supplies filament current for the SV572s and several other indirectly heated preamp tubes. I tried separate supplies for the SV572 and found no audible difference, so I chose to combine the various tubes as shown in *Table 2*. You could supply the SV572 filaments separately if space for the extra transformers is available.

Transformer T4, rated 6.3V AC at 4A, supplies the 6080 filament only because of the high voltage bias required. The two 15EA7s, a 12SN7GTA, and a 12AU6 are all run from transformer T5, which is rated at 12.6V AC at 4A. This transformer gives around 17V DC when rectified and uses dropping resistors to give the two different voltages. Transformer T2, rated 225V-0V-225V at 65mA and 6.3V AC at 2.5A, provides the negative supply and the negative regulator filament. The 6.3V winding is used with a voltage-doubler rectifier arrangement and a dropping resistor to provide 14.8V to the 15EA7.

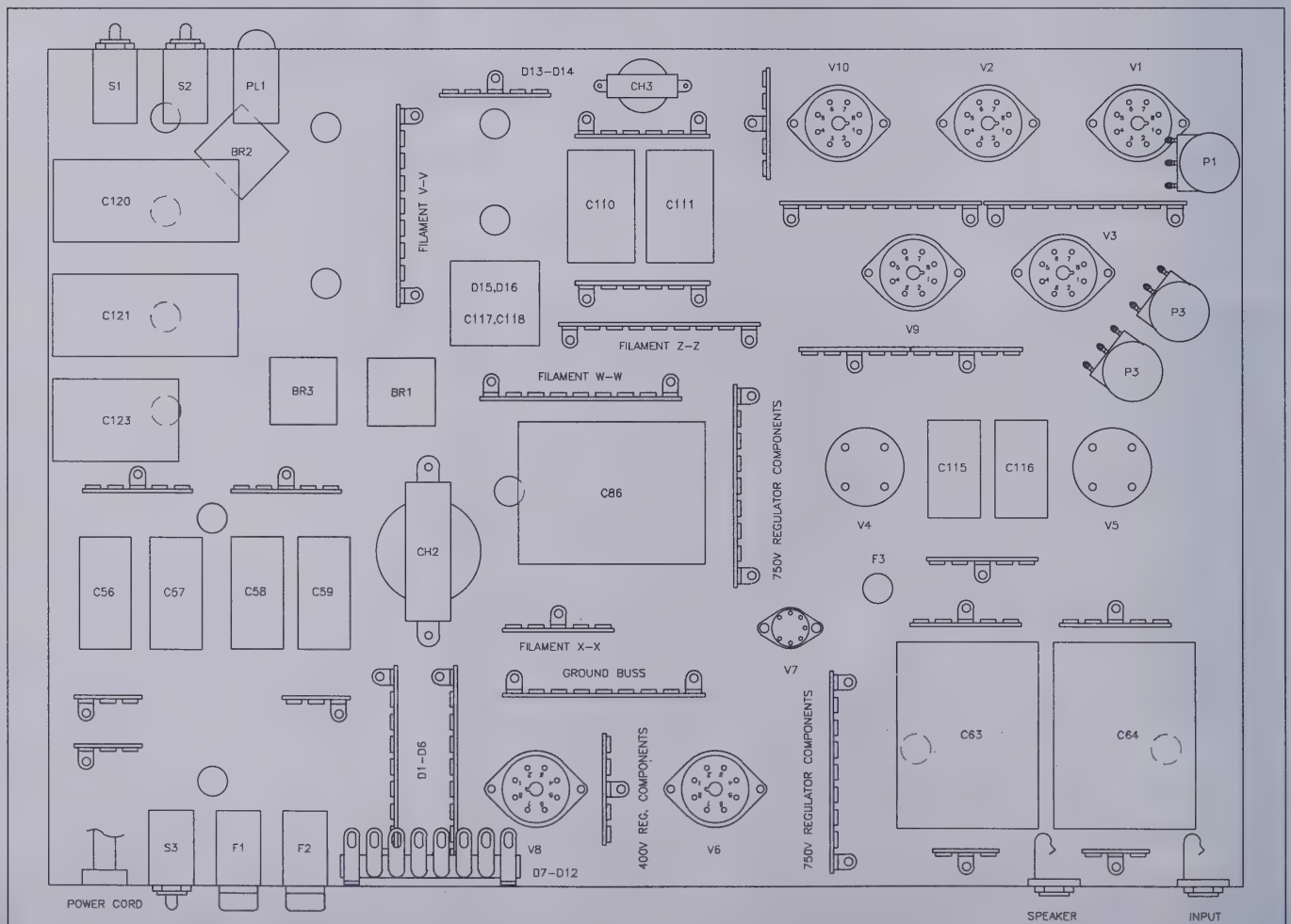

FIGURE 5: Chassis interior (bottom view).

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Reader Service #7

This is only one example of using tubes with nonstandard filaments; many other combinations are available. For example, you could use 8SN7GTBs and 10EM7s. If you don't mind storing them, you can purchase a lifetime supply of these nonstandard filament tubes for the price of one or two of the 6.3V versions.

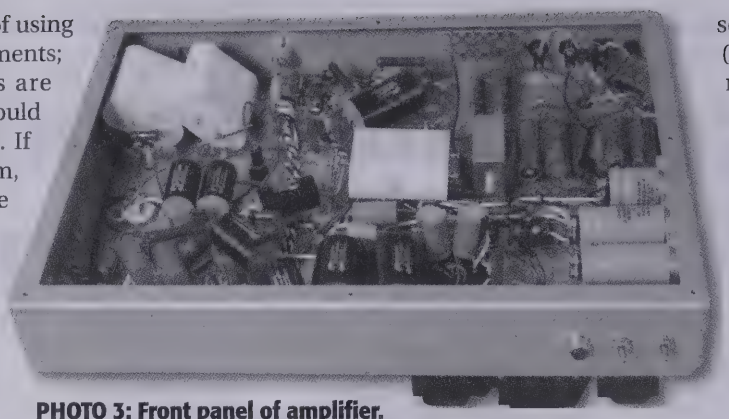

PHOTO 3: Front panel of amplifier.

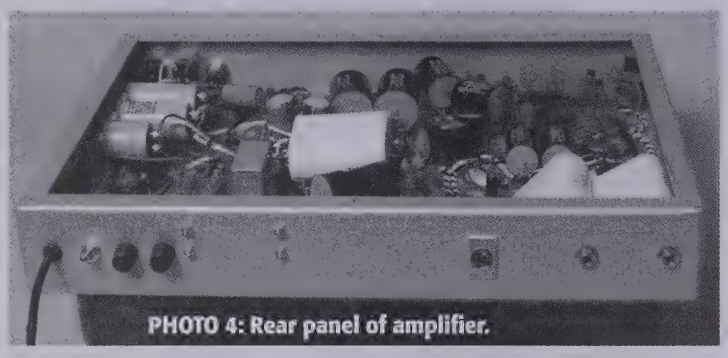

PHOTO 4: Rear panel of amplifier.

COMPONENT CHOICES

I chose SBE 716Ps for the coupling capacitors between the driver differential amplifier and the cathode-follower stages. This is a film/foil type; I find this type sounds much better than metallized film. Of course, there are many tastes in capacitors, and I encourage you to experiment.

All resistors in the amplifier circuit are carbon composition, except for the cathode-follower cathode resistors, which are wirewounds because of the high dissipation required. The carbon comps are paralleled where required to keep dissipation of each resistor to a safe level. I find the carbon comps to have a much smoother sound, especially on high-frequency sounds such as cymbals. Once again, you should experiment to find which components suit your ear. Resistors in the power supply are wirewound or carbon film, depending on the wattage required.

Possible suppliers for the major components are indicated in the parts lists (*Table 3*). The list of suppliers is not exhaustive—many of the components listed, or close substitutes therefor, are available at surplus stores. Hardware items such as jacks, power cords, tube sockets, and so on, are not shown on the parts lists.

CONSTRUCTION

Constructing the sections of the amplifier in the correct sequence and carefully testing each section before moving to the next is extremely important due to the direct coupling between the stages. I recommend the following order of construction.

1. Prepare a detailed layout of component placement (*Photo 2*). I built the prototypes as monoblocks; you could also construct it with a dual power supply on one chassis and a chassis for each amplifier. The layout used for the prototype is shown in *Figs. 4* and *5*. You could change this if you like, but you should adhere to the following construction guidelines:

A. Mount all of the power and filament transformers as far as possible from the input circuitry and the output transformer.

B. The laminations of the filament and power transformers should be perpendicular to the laminations of the filter choke and the output transformer.

C. The center-to-center spacing of the preamp and regulator tubes should be 2½″ minimum, and the center-to-center dimension to the SV572s should be at least 4″.

Due to the number and size of the transformers used, the amplifiers are very heavy. You need to construct the chassis of at least 14 GA steel or 3⁄16″-thick aluminum; standard project boxes are not nearly strong enough. The dimensions of the chassis used for the prototype are 14″ deep × 20″ wide × 3½″ high, constructed of 14 GA steel with fully welded corners. If you decide to use relays for the power-up sequence or tube rectifiers, you will need more space.

2. Drill or punch all holes, including temporary mounting of transformers.

3. Apply desired finish to chassis.

4. Mount power and filament transformers. All wires passing through the chassis should have grommets to protect the insulation. Wire the 120V AC input components such as line cord, ground-select switch, fuse, and so on (*Photos 3* and *4*). Because of the number of transformers, you need a terminal strip of some sort to hook up the five pairs of 120V AC primary windings.

5. Wire the filament DC supplies. It will be necessary to try different voltage-dropping resistors to get the required filament voltage. For 6.3V DC supplies, the resistors will be in the range of 0.1–0.5Ω, and for the 12.6/ 14.8V DC supply, in the 1.0–5.0Ω range. Be sure the 470Ω filament-bias resistors are in place where required. The filament voltage provided by transformer T3 (6.3V DC at 10.1A) may be slightly below 6.3V, even with no dropping resistor, because of the high current draw.

6. Next, wire the power supplies. Build and test the raw-voltage supplies before starting on the regulators. I recommend starting with the negative supply, then the choke-input and the capacitor-input supplies. Note that the voltage on the choke-input supply will rise to a maximum of 920V DC (the same voltage as the capacitor-input supply) below the critical current draw (see chapter 30 of the *Radiotron Designers Handbook*, Fourth Edition, for a detailed explanation), so the capacitor needs to be rated for this voltage. The voltage on this capacitor during normal operation will be around 600V DC. An alternative approach would be to use a bleeder resistor to ensure the critical current draw. If you use this approach, you should increase the inductance of the choke substantially to lower the critical current.

WARNING: The high-voltage raw supply has 1250V AC across the transformer secondary, and 920V DC at the filter. Use extreme caution when testing, since ***these voltages can kill you!***

Many digital multimeters (DMMs) are not rated for voltages this high. Check the specs of your DMM carefully before using it, since the voltage ranges of cheaper ones are typically not well protected. Overvoltage will short the input transistor, and the fuse does nothing in this failure mode. I blew up a Wavetek DMM in exactly this manner.

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- Orders under £400.00 are welcomed, please enquire for prices.
- To qualify for the "100 pieces" price, please ensure your order is both over £400.00 and for 100 pieces.

	Unit Price For 1 Piece	Unit Price For 100 Piece		Unit Price For 1 Piece	Unit Price For 100 Piece
4HA7/PC900 Russia/East European	£1.15 each	£0.90 each	85A2 Mullard	£3.00 each	£1.00 each
5Z4GT Russia	£2.30 each	£1.60 each	5670W GE USA	£1.50 each	£1.00 each
6AL5 Mullard UK/CV 4025	£1.00 each	£0.75 each	5751 GE/JAN USA	£4.00 each	£2.80 each
6AU6WC USA	£0.95 each	£0.95 each	5965 GE USA	£0.99 each	£0.99 each
6BQ5 (EL84 Billington Gold Russian) Extended guarantee. NFD	£2.40 each	£2.00 each	6550B Russia	£8.00 each	£6.00 each
6BQ5/6C116 Brimar UK – these 6C116 are similar to 6BQ5 but have different pin out.			E88CC Tesla, gold pin 1962. OB	£5.90 each	£4.20 each
Data on request.	£1.95 each	£1.40 each	EB91 – SEE 6AL5		
6DJ8/ECC88 Tesla 1962, OB, NFD	£2.00 each	£1.45 each	ECC81/83 – SEE 12AT7/12AX7		
6DJ8/ECC88 Tesla 1962, Unboxed, NFD	£1.75 each	£1.20 each	ECL86 – SEE PCL86 similar item – data on request		
6SG7 GE USA	£1.80 each	£1.60 each	EL34 Tesla, clear glass	£5.40 each	£4.80 each
6SL7GT Russia, Unbranded	£1.60 each	£1.40 each	KT88 – SEE 6550B		
6V6GT Russia	£2.95 each	£2.10 each	PCL86 Russia	£0.37 each	£0.37 each
12AT7/12AT7WC Phillips	£1.65 each	£1.65 each	PL509/19 Tungsram	£5.60 each	£3.95 each
12AT7 Tungsol	£2.80 each	£2.80 each	SV572-30 Svetlana	£32.00 each	–
12AU7 Thermionic. NFD	£2.40 each	£2.20 each	SV811-10 Svetlana	£15.16 each	–
12AX7/12AX7WA Sylvania USA	£4.50 each	£3.20 each			

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Reader Service #5

This is a good situation for the nearly forgotten vacuum-tube voltmeter (VTVM), since typical ones are rated to 1200V AC/DC. On a VTVM, the input tube electronically isolates the meter movement, so they are almost impossible to blow up. They are available at surplus stores and hamfests, typically for less than $20. After frying the Wavetek DMM, I purchased a VTVM for high-voltage use, and another DMM for general use.

7. Begin wiring the +750V DC regulator. You should construct a temporary voltage divider from the raw supply to bias the 12AU6 filament up to +200V DC. Do not delete the resistor connected from the plate to the cathode of the pass tube, since this prevents arcing at start-up. You should adjust the small-value resistor R71 in value if necessary to give the proper output voltage.

Test the regulator at various current draws to verify regulation; this will require high-wattage wirewound resistors. A 10k, 100W resistor will test the regulator at 75mA. If the voltage stays constant at 75mA current draw, the regulator is probably working fine, and you can perform higher-current tests later with the power tubes in place.

8. Now begin wiring the +400V DC regulator. As with the 750V regulator, keep the resistor connected from the plate to the cathode of the pass tube, and adjust the small-value resistor R92 in value to give the proper output voltage.

Test the regulator at various current draws to verify regulation. The 10k, 100W resistor mentioned above will test the regulator at 40mA, which is fairly close to the current draw in normal operation. The output voltage of this regulator will not be as constant as the +750V DC unit because of the lower gain of the error amplifier, but it is adequate for use in this Class A differential design.

9. Begin the wiring of the +200V DC regulator. Again, for the same reasons, do not delete the resistor connected from the plate to the cathode of the pass tube, adjust the small-value resistor R100, and test the regulator at various current draws to verify regulation. A 5k, 100W resistor will test the regulator at 40mA, which is fairly close to the current draw in normal operation. After you test the regulator, remove the temporary +200V DC filament bias constructed in step 7 and wire as shown on the schematic so bias is applied through a 100k resistor (R132) connected to the pass-tube cathode.

10. Now wire the –200V DC regulator. Start with the voltage divider from the raw source that supplies the –100V DC filament bias. Do not delete the resistor connected from the plate to the cathode of the pass tube. Adjust the small-value resistor R116 if necessary to give the proper output voltage.

Test the regulator at various current draws to verify regulation. The 5k, 100W resistor used in step 9 will test the regulator at 40mA, which is fairly close to the current draw in normal operation. The schematic may look confusing, since it shows the cathode of the pass tube grounded, but I assure you this is the proper circuit for a vacuum-tube negative-voltage regulator. The regulator "bleeds off" positive voltage to maintain the negative voltage desired.

With the power supply complete, you can now wire the amplifier circuit. The construction should proceed as I describe below so that no individual stage operates under dangerous conditions during testing or the construction of other stages.

11. You should wire the cathode followers for the SV572s before the power tubes themselves, since the bias for the power tubes is applied through the cath-

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ode followers. The +200V DC and –200V DC regulated supplies power the cathode followers. You must fully wire the bias circuitry, including the adjustment pots, before the next step, which is setting the bias-adjustment pots to give –50V DC on the cathodes.

12. Next, wire the power tubes and output transformer. Remove the fuse in the center-tap lead of the output transformer (F3) and connect an ammeter across the fuse terminals. This monitors the current drawn by both power tubes. Connect an 8Ω dummy load across the output to protect the output transformer.

13. Now test the output stage for proper operation, adjusting the bias to approximately –35V DC, at which point the pair of SV572s should draw around 200mA with 750V DC plate voltage. After testing is complete, not replacing the output-transformer fuse will disable the output stage while you work on the input and driver stages.

14. Next, construct the input differential amplifier. This stage is powered by the +400V DC and –200V DC supplies. Wire the circuit, then power up the amplifier and check the voltages against those given on the schematic. You may need to adjust the value of the cathode resistor to account for resistor tolerance or to achieve the proper bias of 8V. You do this by changing to a larger or smaller value one of the three resistors that are paralleled. After setting the bias voltage to the correct value, adjust the balance pot to give the same plate voltage on each triode. The plates of this stage are direct-coupled to the driver differential amplifier.

15. Now wire the driver differential amplifier. This stage is powered by the +720V DC supply, and the common cathode resistor is returned to ground. Wire the circuit, then power up the amplifier and check the voltages against those given on the schematic. You may need to adjust the value of the cathode resistor to account for resistor tolerance or to achieve the proper bias of 9V. This you do by raising or reducing the value of one of the four paralleled resistors. The grids are at the potential of the plates of the previous stage (around +240V DC). The output of this stage is capacitor-coupled to the output cathode followers.

16. Now test the completed driver circuit. Disable the output stage by removing output transformer fuse F3, leaving the SV572s in place so the filament voltage does not rise. Temporarily connect one lead of a large-value film capacitor to the cathode of one of the output cathode followers and connect a 100k resistor from the other capacitor lead to ground. This forms an RC-coupling network to protect the test equipment from the DC offset of the cathode follower.

Using a 1kHz sine wave, measure the distortion at 50V RMS output at the junction of the capacitor and the 100k resistor. This should be less than 1.5% THD. If you don't have a distortion analyzer, increase the sine-wave input and note the voltage output at clipping. If the output doesn't clip until 75V RMS output, the circuit is probably working correctly.

17. The next step is to set the output stage for optimal balance. Enable it by replacing the output-transformer fuse, and connect an 8Ω 100W dummy load to the output. Power up the amplifier and reset the bias on each power tube. Do this by the "transformer shunt" technique of connecting an ammeter from the output-transformer center tap to the plate of one of the output tubes. The meter's low resistance causes all the current to flow through it, thereby indicating the current

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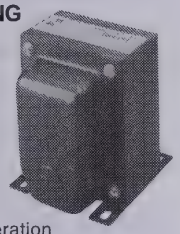

Hammond audio transformers all feature "X" type bell end mounts with a black matte finish. All units include 40% screen grid tap for Ultra-Linear operation and 4, 8, and 16 ohm secondary taps. Frequency response is 30-30,000 Hz (+/-1 dB max. ref. 1KHz) ***at full output power***, not at 1 watt like many manufacturers use!

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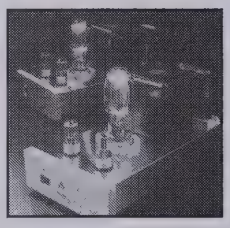

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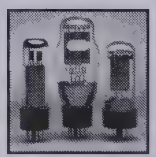

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flow for that power tube only.

Set bias on each side for 100mA current through each power tube. If the power tubes are matched, the bias should vary by only a couple of volts from one side to the other. Be extremely careful during this procedure, since the amplifier must be "live" during the test. The trick of putting 1Ω resistors between the power-tube cathode and ground will not work here, because the power tubes are directly heated. With the bias properly set, you can now test the output power and distortion.

TABLE 4
DISTORTION AT VARIOUS POWER LEVELS

(RMS)	V_{out} (RMS ACROSS 8Ω DUMMY LOAD)	POWER OUTPUT (RMS)	THD
0.08	2.8	1W	0.3%
0.28	8.9	10W	0.4%
0.65	20.0	50W	2.6%

18. Using a 1kHz sine wave, measure the distortion at the power levels as given in *Table 4*. If you have no distortion analyzer, increase the sine-wave input and note the voltage output across the dummy load at clipping. This should occur at about 22V RMS. An oscilloscope is a big help in determining when the amplifier starts to clip. Viewed on the scope, the top section of the sine wave will start to flatten as maximum power is approached. This is a visual indication that the grid-current demands of the power tubes are becoming higher than the 6BL7 cathode follower can supply.

POSSIBLE MODIFICATIONS

One possible modification to this amp design would be to include feedback, introduced at the input differential amplifier on the grid that is currently grounded. You should then change the input-differential driver tube to a 6SL7 to increase the open-loop gain, or input sensitivity will decrease. You would also need to adjust the plate- and cathode-resistor values to provide the same plate voltage so as not to affect the operating point of the driver differential stage.

I tried this on the prototype and found I preferred the sound of the no-feedback circuit, but I encourage you to experiment with both approaches, since the required changes are easy to make. You may need to reverse the output-transformer primary's connection to the power tubes to provide negative feedback. If it's hooked up incorrectly, the feedback will be positive and the amplifier will oscillate.

Another mod is to add constant-current sources to the differential amplifiers for a possible increase in linearity. You could accomplish this by adding a 6BL7 to replace the amplifiers' cathode resistors.

You could also use tube rectifiers in place of the solid-state ones. This would require a major redesign, including changes to the power transformers, as well as adding filament transformers and chassis space. The current and PIV requirements dictate a pair of 6AU4GTs for the +750V DC supply, and a pair of 6AU4GTs for the +400V DC supply; the negative supply could use a 6AX5GT.

Since these rectifiers are indirectly heated, you could run them all on a single large filament transformer. Using 5R4s for the positive supplies would also be possible, but they would require individual filament transformers, and since they are directly heated, they will not provide enough thermal delay.

Voltage-reference (VR) tubes could also replace the zener-diode references. The zeners work fine under normal con-

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ditions, but if the regulator tube arcs, the zener may also fail. A short on the regulator output may also cause zener failure. If I were starting over, I would probably use VR tubes, since I shorted several zeners during construction. The VR tubes' only drawback is the space required.

Finally, you could add relays to automate the power-up sequence. This would probably require increasing the chassis size.

THE SOUND

If you are interested in making the sizable time and money investment to build a pair of these amplifiers (about $2500–$3000 for the pair of monoblocks), you probably wonder how the finished product sounds. My impression is as follows:

Bass: The bass is very tight and clear, with good definition between the different low-frequency instruments such as bass drum and electric bass.

Midrange: The midrange is warm and clear, and you can easily discern the different instruments. A noticeable effect of having no feedback is that the vocalist or lead instrument stands out in the mix in a way I've never heard from an amplifier using feedback. I tried feedback on this amplifier, and this wonderful clarity disappeared.

Treble: The treble is warm and clear, but not overly bright. I noted that cymbals retained the "metal" aspect of their sound that you hear in person, and were not "hissy" at all.

I noted these impressions while listening to jazz and rock recordings. Classical sounded good also, but I don't listen to enough classical to make an informed judgment.

Noise and hum are basically inaudible, due to the regulated supplies and the DC filaments. ❖

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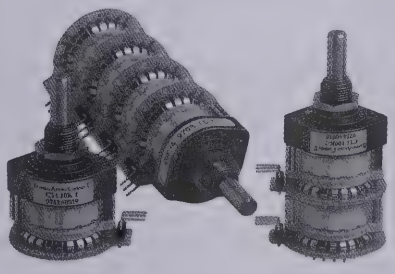
Our stepped attenuators are built on Swiss precision mechanics. They have 24 steps and uses low noise, low inductance SMD metal film resistors. Due to the compact design and the use of SMD resistors, CT1 and CT2 have several times shorter signal path than a conventional stepped attenuator using leaded resistors.

All CT1 and CT2 contacts and conductors are gold plated. Examples of specifications are: Bandwidth 50MHz, attenuation accuracy ±0.05dB, tracking between channels ±0.05dB, THD <0.0001%.

CT1 and CT2 audio attenuators are good choices for volume controls in audiophile preamplifiers, in professional audio equipment and for audiophiles who which to upgrade their existing amplifiers that use less ideal volume controls.

Besides the CT1 and CT2 audio attenuators we are also offering the CT3 audio input selector switch, which is of the same built quality as CT1 and CT2. CT3 switches between up to 5 signal sources.

Photo: CT1 Audio Attenuators in mono, stereo and balanced stereo versions. Available in 10, 20, 50, 100 and 250 kOhm.



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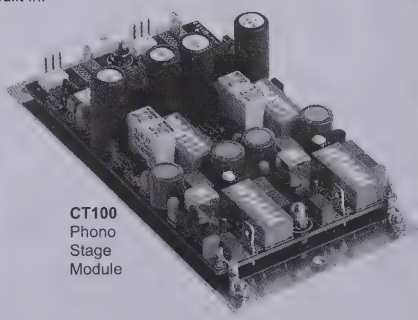

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57025	ECC88/6DJ8	Dual Triode	Mullard (UK)	$18.00 ea.
52603	E188CC/7308	Dual Triode	Sylvania/Philips ECG (USA)	$20.00 ea.
56208	6BX7GT JAN	Dual Triode	GE (USA)	$13.00 ea.
56292	JAN 5687WB	Dual Triode	Philips (USA)	$4.88 ea.
52515	KT88	Power Pentode	National (USA)	$75.00 ea.
52628	GZ-37/CV-378	Dual Rectifier	Mullard (UK)	$20.00 ea.
57018	M8136/CV-4003	Dual Triode	UK	$20.00 ea.
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52591	E88CC/6922	Dual Triode	Mullard	$22.50 ea.
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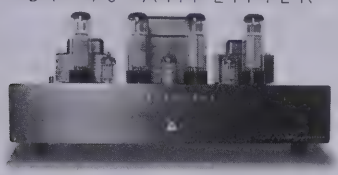

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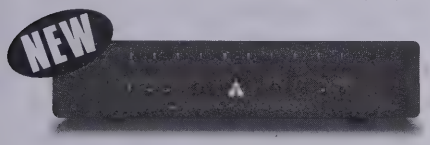

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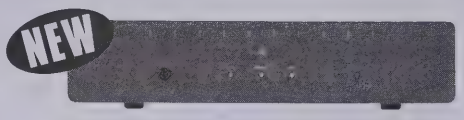

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An Expandable Beginner's Amp

Here's an amplifier that might be a good first project for a beginner–it has only six parts! The power supply has only six parts, too! By taking it one step at a time–first you build and get the output stage and power supply working, and then you add an input stage–it's easier to find a problem if the amplifier doesn't work when plugged in.

BY LARRY LISLE

The circuit in *Fig. 1* shows a basic amplifier, the input voltage of which is stepped up by an output transformer connected backwards, giving a voltage increase of about 17 times. Because of the capacity across the input circuit, the output falls off badly above 5kHz. Still, below that level it doesn't sound too badly; perhaps it could be used as the bottom half of a biamp system.

Its real purpose, though, is to get the circuit running. You'll replace the transformer with a tube in the next step. The alternating input voltage is applied to the grid of the 811-3, in series with the bias voltage from a 45V battery. The plate is connected to the output transformer, which in turn is connected to the B+ supply of 300V. Filament power is supplied by a step-down transformer, and the resistor across the filament is adjusted to null any hum.

Figure 2 shows the power supply. The output of a step-up transformer goes through a resistor R1 to a bridge rectifier, and then to a capacitor-choke-capacitor filter to smooth out the pulsating DC from the rectifier. The purpose of the resistor is to lower the voltage of the transformer so the output is around 300V. Depending on the transformer you use, it may not be necessary. I placed it so as to make life easier for the bridge rectifier and filter capacitors.

Every design is a function of many compromises and choices. I'd like to share the reasons for the choices I made as shown in the diagrams and photos. Feel free to change anything you wish. My overriding consideration was simplicity and ease of construction consistent with a finished product that would give good sound reproduction.

Why build it on a board?

1. It's much easier to build this way. A beginner will have enough difficulty with electrical construction without adding mechanical problems.
2. The circuit is easier to modify.
3. Heavy transformers are best supported by wood. Lighter circuits that need shielding can be built in small aluminum enclosures.
4. Heat is confined and doesn't spread through the whole chassis, causing component values to drift.
5. There are fewer problems with hum and feedback using "breadboard" construction.

Why choose an 811-3?

1. With only 300V on the plate, it's bullet-proof. You can short the bias supply and

TABLE 1
PARTS LIST

CAPACITORS

C1, C2	47µF, 450V electrolytic capacitor
C3	1µF, capacitor
C4	47µF, 25V electrolytic capacitor
C5, C6	1µF, 600V capacitor
L1	5-Henry, 150mA filter choke
B1	400V, 1 amp bridge rectifier or 4 diodes

RESISTORS

R1	Power resistor, if needed, to reduce output to 300V (depends on transformer used)
R2	50Ω, 5W potentiometer (variable resistor), Antique Electronics R-V501 (or equiv.)
R3	470kΩ, 1W
R4	3.3kΩ, 1W
R5	220kΩ, 1W
R6	10kΩ, 1W
R7	470kΩ, 1W

TRANSFORMERS

T1	Output transformer connected backwards; See text
T2	Output transformer 2.5k to 5kΩ primary to voice coil, rated 100mA for single-ended use.
T3	Power transformer 300V secondary at 100mA
T4	Filament transformer 6.3V at 5A or greater
V1	Svetlana 811-3 vacuum tube
V2	6SL7 vacuum tube
BT1	45V battery (Antique Electronic Supply S-Z283 or equivalent)

MISC

16″ × 7¼″ × ¾″ (measured) baseboard; 7¼″ × 5⅝″ subassembly board; sockets for tubes, terminal strips, Fahnestock clips, wire, solder, aluminum chassis 7″ × 5″ × 2″

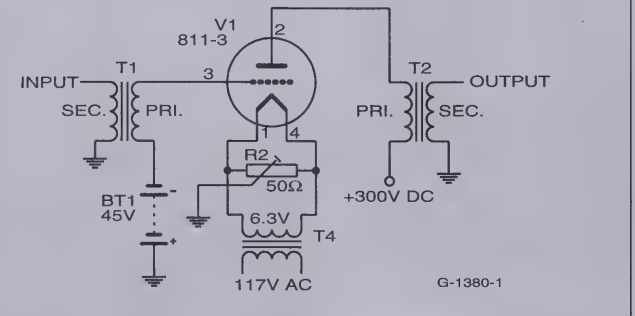

FIGURE 1: The basic amplifier.

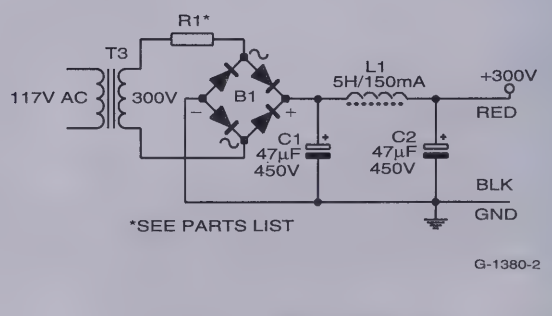

FIGURE 2: A basic power supply.

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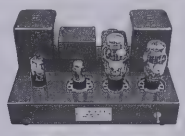
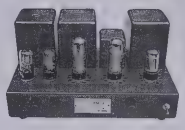
★You can replace the power tubes for SV-series power amplifiers by other tubes with some alternation of the circuit in order to get deferent tonal character.
As for power voltage, SV-kits are prepared for operation in U.S.A., European and Asian countries.

POWER AMPLIFIER SERIES



NEW ITEM SV-300BTE
- Power 8W
- Tubes 300B : 1 6SN7GT : 1 6V6GT : 1 5U4G : 1



NEW ITEM SV-PM200
- Power 5W + 5W
- With 3 INPUT, REC IN and REC OUT terminals
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SV-300B MKII
- Power 20W, with Interstage Transformer
- Tubes 300B : 2 6SN7GT : 1 5U4G : 1

SV-2A3PE
- Power 15W, with Interstage Transformer
- Tubes 2A3 : 2 6SN7GT : 1 5U4G : 1

SV-KT88PE
- Power 30W, with Interstage Transformer
- Tubes KT-88 : 2 6SN7GT : 1 5U4GB : 1

SV-6L6PE
- Power 20W, with Interstage Transformer
- Tubes 6L6GC : 2 6SN7GT : 1 5U4GB : 1

SV-300BSM
- Power 8W, with specially manufactured OPT
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SV-2A3
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- Tubes 2A3 : 2 6SN7GT : 2 5U4G : 1

SV-KT88
- Power 8W × 8W
- Tubes KT88 : 2 6SN7GT : 2 5U4GB : 1

SV-300BE
- Power 8W × 8W
- Tubes 300B : 2 6SN7GT : 2 5U4G : 1

SV-6V6SE
- Power 4.5W × 4.5W
- Tubes 6V6 : 2 6N7GT : 2 GZ34 : 1

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Reader Service #46

the tube keeps right on ticking. But don't try that with a 300-B!
2. It sounds great.
3. It's available at low cost.
4. If a manufacturer introduces new audio tubes, the audio community should at least give them a try, especially if we want other new tubes.

Why does the 811-3 have only 300V on the plate?
1. Safety for the user. 300 was the traditional maximum for consumer electronics in the old days, except for picture tubes and specialty applications. It's not a bad idea today for a beginner.
2. Safety for the tube. There's not much chance of blowing up the 811-3 with only 300V on the plate. Unless of course you use it to light the filament.

Why is the filament transformer on the board with the amplifier instead of on that of the power supply?
1. You can plug in the tube filament and see if it lights. If it doesn't, you can check your wiring before you plug in the plate supply and find too late that you wired the socket wrong and there's 300V on the filament (see above).
2. The filament carries heavy current, requiring large-diameter wires. If you use the wires from the transformer, you needn't worry.
3. You can warm up the tube before hitting it with the plate voltage. There are many circuits that let you do this with only one switch, but this is the simplest way.
4. You can easily try tubes with different filament voltages just by switching filament transformers. For instance, the 2A3 is a drop-in if you switch to 2.5V for the filament and lower the plate voltage a little.

Why use a resistor across the filament?
l. If you don't use well-filtered DC on the filament of a directly heated tube, you must have some way of balancing the hum. The use of a variable resistor with the middle tap connected to ground does a very nice job simply. Hum is down well over 60dB.

Why use battery bias instead of self-bias?
1. If you use some form of self-bias, the bias voltage is effectively subtracted from the voltage necessary to operate the tube. For instance, 45V of self bias subtracted from 300 leaves only 255V between filament and plate, whereas battery bias lets you use every bit of the 300V effectively.
2. Simplicity
3. It sounds good.

Why not put the power supply and amplifier on the same board?
1. Hum and noise from the power supply might creep into the signal path.
2. Building the power supply separately makes it easy to switch to a higher-voltage tube-type supply later if you prefer.
3. You might wish to borrow the 300V supply to test a different amplifier sometime in the future.

Why use an output transformer with a primary impedance of 2.5kΩ?
1. I used a Hammond 1627-SE in the prototype. It sounded and measured fine, even though it's less than the usual twice the plate impedance.
2. Since this is an "expandable" amp, you might wish to try other tubes later, and 2.5kΩ is a close match for a 2A3 at 250V on the plate, or a 300-B with 250 or 300V on the plate and slightly increased bias.
3. If you plan to stick with an 811-3, I'd suggest a transformer with a 5kΩ primary.

What is the input transformer?
I salvaged the transformer from some Fisher gear long ago. The transformer isn't critical, since it's only there to test the amplifier and power supply, so use what you have on hand. If you're buying two output transformers for a future stereo setup, use one as the input and the other as the output.

PHOTO 1: There's nothing like the glow of a thoriated tungsten filament in a tube amplifier you've built yourself!

CONSTRUCTION PROCEDURE

In building the unit, I used a piece of oak 16″ × 7¼″ × ¾″ (actual measurement). The input subassembly board is made of the same stock and measures 7¼″ × 5⅝″. A larger baseboard would be fine; a smaller one might cause heat problems.

Mount the output and filament transformers as shown in *Photos 1–3*. If you're not positive about which terminals on the tube socket are for the filament, temporarily wire the power cord, transformer, and socket, and try to light the tube to make sure. (Primary wires are usually black, secondary green. Check the manufacturer's information.)

After you've established which terminals are for the filament, mount the socket with the filament terminals toward the filament transformer. The plate terminal is the remaining terminal closest to the output transformer. Remove the transformers and socket, and drill 5⁄32″ holes for the wires from the transformers to pass under the board and up to the tube socket. The plate lead from the output transformer is usually blue; the red wire goes to the B+.

Wire the outside terminals of the hum-balancing variable resistor to the filament terminals, drilling appropriate holes to put the wiring under the board. The center terminal goes to the two Fahnestock clips near the center of the board, which are held by a 6-32 bolt that goes through the board. Connect the grounded wire of the three-wire power cord to the bolt underneath the board. Use a plastic cable clamp to secure the cord so a sudden jerk on it won't pull on the wires.

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Reader Service #32

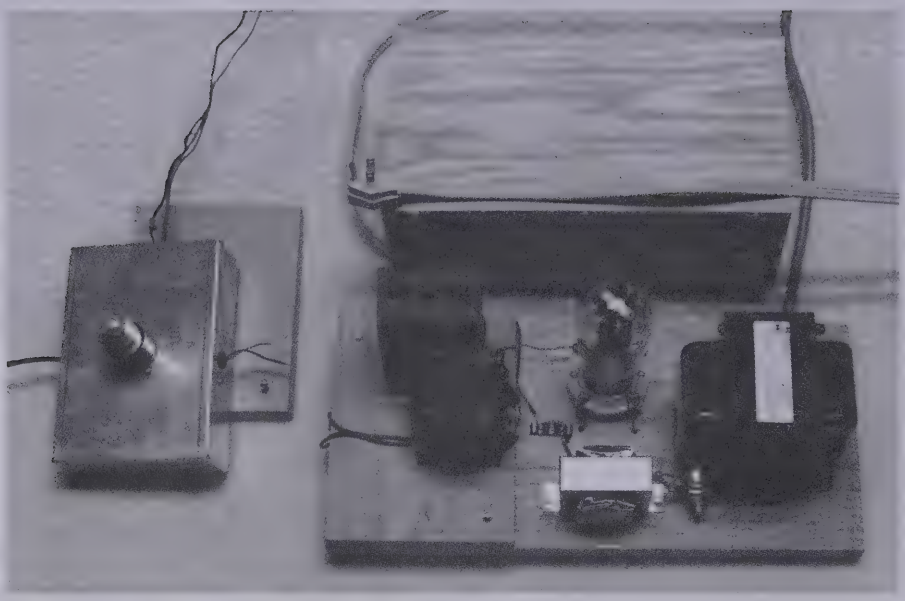

PHOTO 2: The basic power amplifier. Behind it is the power supply in a wooden box for safety. The voltage amplifier is on the left. Modular stages make construction easy.

Mount the input transformer on the subassembly board. Connect the blue wire to the grid terminal of the tube socket, and the red to the negative post of the 45V battery. Connect the positive post of the battery to the ground Fahnestock clips. Use the full winding of the secondary of the input transformer (which is here used as the primary) for the input. Connect the secondary wires of the output transformer to your speakers (follow the manufacturer's literature for which colors to use).

POWER SUPPLY

The power supply is very simple; you can almost wire it from *Photo 3*. Determine from the manufacturer's information which wires are the primary, and connect them to the power cord. The ground wire of the power cord will go to the circuit ground. The high-voltage secondary wires go to the AC terminals of the bridge rectifier. Make one of the wires a temporary connection, because it may be necessary to put resistor R1 in the circuit to lower the output voltage.

The negative output of the bridge rectifier goes to the circuit ground, while the positive terminal goes to the junction of one wire from the choke and the positive terminal of the input capacitor C1. The other wire from the choke is connected to the positive terminal of the output capacitor C2. The negative terminals of both capacitors are connected to circuit ground.

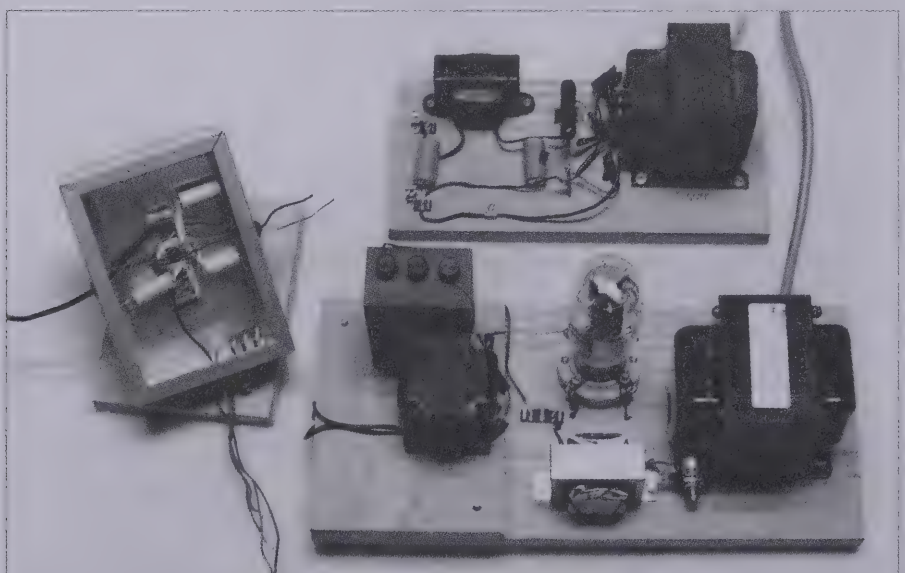

PHOTO 3: The parts placement of the power supply and voltage amplifier can be changed to suit your needs.

With a piece of red hookup wire, connect the positive output of the power supply to the red wire from the output transformer of the amplifier. Connect the circuit ground of the power supply to the circuit ground of the amplifier with a piece of black hookup wire. *All points carrying dangerous voltage should be insulated or covered.*

The amplifier is now ready for use. Temporarily short the input wires. Plug in the filament transformer and wait a couple of minutes to let the tube warm up. Plug in the power supply and check the high voltage on the plate pin of the 811-3. If it is much above 300V, you'll need to use a power resistor at R1 to drop the voltage. You can use Ohm's law to figure the value, or start with about 1kΩ at 10W and adjust the value up or down as needed. *Unplug the power supply and short the positive terminal of both capacitors in the power supply to circuit ground before you touch anything on the power supply or amplifier boards. Capacitors can hold a charge for days!*

After adjusting the plate voltage if necessary, adjust the hum-cancelling variable resistor to about the center of its range until you can no longer hear any hum in the speakers. An AC voltmeter on the output will let you find an exact null, but you can do it satisfactorily by ear. Now unshort the input, connect it to your music source, and enjoy!

GOING FURTHER

The next step is to build an input amplifier to replace the turned-around input transformer. A suggested circuit is shown in *Fig. 3*. It uses half of a 6SL7 in a very standard circuit. The aluminum chassis I used measures 7″ × 5″ × 2″. This could be much smaller, but it would make the wiring more difficult.

Space considerations prevent a complete "kit" type set of instructions, but here are some tips to get you started:

Solder the ends of two pieces of green hookup wire to pins 7 and 8. Twist them together and run them close to the side of the chassis and out of the box through a grommet. These are the filament wires that you can attach to the 811-3 filament circuit. (You may need to rebalance the variable resistor.)

Connect the positive end of the 47μF capacitor C4 and one end of the 3.3kΩ resistor R4 to pin 3 of the socket. Connect the other ends of both to the circuit ground connection. Connect one end of the 1μF capacitor C3 and one end of the

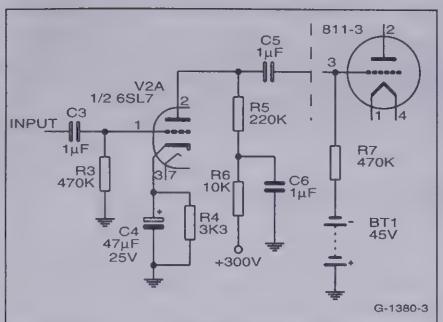

FIGURE 3: A no-frills voltage amplifier to add to the power output stage.

470kΩ resistor R3 to pin 1 of the tube socket. The free end of the resistor goes to circuit ground; the free end of the capacitor goes to your input connector or cable. Connect the 1µF capacitor C5 and the 220kΩ resistor R5 to pin 2 of the socket. The free end of the capacitor goes to an insulated terminal. (Insulated terminal strips are available from Antique Electronic Supply, 6221 S. Maple Ave., Tempe, AZ 85283, 602-820-5411, FAX 602-820-4643.)

From the terminal, a piece of hookup wire (not red, green, or black) passes out of the box through a grommet to the grid of the 811-3. The free end of the 220kΩ resistor goes to an insulated terminal where it's connected to the 1µF capacitor C6 and 10kΩ resistor R6. The free end of the capacitor goes to circuit ground; the free end of the resistor goes to an insulated terminal.

Connect a piece of red hookup wire to the terminal and run it out of the box through the same grommet as the filament wires. This goes to the B+ connection on the power supply. Connect a piece of black hookup wire to the circuit ground, and run it out of the box through the same grommet to the circuit ground of the power supply.

Connect the 470kΩ resistor R7 to the grid terminal of the 811-3. The free end goes to the negative post of the 45V battery; the positive post goes to ground as before. *Don't do any soldering to a tube terminal with the tube in the socket.*

You should now have a very nice-sounding, if somewhat low-powered amplifier. You can take a lot of paths from here. First, you can just enjoy the music! Or you can try other tubes in place of the 811-3; increase the plate voltage on the 811-3 with a new power supply (perhaps with a tube rectifier and oil-filled capacitors); try second-harmonic cancellation, as in my article in *GA* 5/98, "Canceling Harmonics in SE Amplifiers," p. 30; try other types of voltage amplifiers, and so on. Have fun! ❖

Reader Service #47

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Reader Service #33

Theory of the SRPP Circuit

In mathematical terms you can follow, this author outlines the proper design of the SRPP circuit.

BY P. J. TOUZELET

This article describes a theoretical analysis conducted to establish the principal formulas governing the shunted regulated push-pull (SRPP) circuit behavior. From these formulas, I will show that this behavior is very close to that of a classical circuit, except for particular conditions where it becomes equivalent to a true linear circuit.

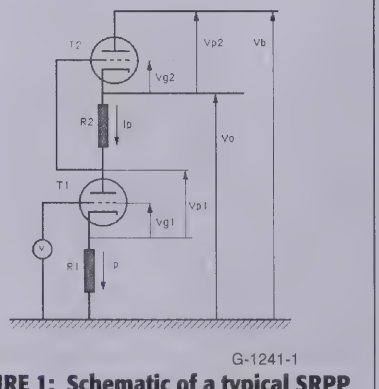
The usual schematic for the SRPP circuit is shown in *Fig. 1*. It is composed of two identical triodes in series. The notation is as follows:

T_1, T_2	Triodes
R_1, R_2	Grid-bias cathode resistors
V_b	Supply voltage
V_{g1}, V_{g2}	Grid/cathode voltages
V_{p1}, V_{p2}	Plate/cathode voltages
V_0	Output voltage
I_p	Plate current
v	Input voltage

I made the analysis according to the following assumptions: first, that parasitic capacitors between electrodes are disregarded, and second, that plate current for each triode is given by the following formula:

$$I_p = f(u) = k(V_g + V_p/\mu)^{3/2}$$

where k = perveance; μ = amplification factor; V_p = plate/cathode voltage; and V_g = grid/cathode voltage.



G-1241-1

FIGURE 1: Schematic of a typical SRPP circuit.

EQUATIONS

Taking the above assumptions into account, the equations describing the SRPP behavior are:

$$V_{p2} = V_b - V_0 \quad [1]$$

$$V_{g2} = -R_2 I_p \quad [2]$$

$$V_{p1} = V_0 - (R_1 + R_2) I_p \quad [3]$$

$$V_{g1} = -R_1 I_p + v \quad [4]$$

$$I_p = f(u_1) = f(V_{g1} + V_{p1}/\mu) \quad [5]$$

$$I_p = f(u_2) = f(V_{g2} + V_{p2}/\mu) \quad [6]$$

When v = 0, the triodes are at their resting bias points, and the equations become:

$$V_{p20} = V_b - V_{00} \quad [7]$$

$$V_{g20} = -R_2 I_{p0} \quad [8]$$

$$V_{p10} = V_{00} - (R_1 + R_2) I_{p0} \quad [9]$$

$$V_{g10} = -R_1 I_{p0} \quad [10]$$

$$I_{p0} = f(u_{10}) = f(V_{g10} + V_{p10}/\mu) \quad [11]$$

$$I_{p0} = f(u_{20}) = f(V_{g20} + V_{g20}/\mu) \quad [12]$$

It is a common practice to take as reference the parameter values at the resting bias point and to consider the small parameter variations around them. Under these conditions, the equations can be rewritten using differential notation and Taylor's expansion for triode characteristics:

$$dV_{p2} = -dV_0 \quad [13]$$

$$dV_{g2} = -R_2 dI_p \quad [14]$$

$$dV_{p1} = dV_0 - (R_1 + R_2) dI_p \quad [15]$$

$$dV_{g1} = -R_1 dI_p + dv \quad [16]$$

$$dI_p = f'(u_{10}) du_1 + \tfrac{1}{2} f''(u_{10}) du_1^2 + \ldots \quad [17]$$

$$dI_p = f'(u_{20}) du_2 + \tfrac{1}{2} f''(u_{20}) du_2^2 + \ldots \quad [18]$$

The derivatives $f'(u_{10})$; $f''(u_{10})$;...$f'(u_{20})$; $f''(u_{20})$;...are calculated to the resting bias point and I will denote them, for further development, f'; f";...as $u_{10} = u_{20}$.

Notice that from [17] and [18], we have $du_1 = du_2$, that is to say,

$$dV_{g1} + dV_{p1}/\mu = dV_{g2} + dV_{p2}/\mu.$$

It is then possible to rewrite the above equations in the equivalent following form:

$$dV_{p2} = -dV_0 \quad [19]$$

$$dV_{g2} = -R_2 dI_p \quad [20]$$

$$dV_{p1} = dV_0 - (R_1 + R_2) dI_p \quad [21]$$

$$dV_{g1} = -R_1 dI_p + dv \quad [22]$$

$$dV_{g1} + dV_{p1}/\mu = dV_{g2} + dV_{p2}/\mu \quad [23]$$

$$dI_p = f' du_2 + \tfrac{1}{2} f'' du_2^2 + \ldots \quad [24]$$

SOLUTION

Equations [13] to [17] provide a linear system of five equations with five unknowns which are: dV_{p1}, dV_{g1}, dV_{p2}, dV_{g2}, dV_0. Using a matrix, you can write this linear system as

$$\begin{Vmatrix} 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & -1 \\ 0 & 1 & 0 & 0 & 0 \\ \frac{1}{\mu} & 1 & -\frac{1}{\mu} & -1 & 0 \end{Vmatrix} \otimes \begin{Vmatrix} dV_{p1} \\ dV_{g1} \\ dV_{p2} \\ dV_{g2} \\ dV_0 \end{Vmatrix} = \begin{Vmatrix} 0 \\ -R_2 dI_p \\ -(R_1 + R_2) dI_p \\ -R_1 dI_p + dv \\ 0 \end{Vmatrix} \quad [25]$$

Solving this linear system allows you to express the unknowns dV_{p1}, dV_{g1}, dV_{p2}, dV_{g2}, dV_0, as functions of dI_p and dv:

$$dV_{p1} = \frac{\mu(R_1 - R_2) - (R_1 + R_2)}{2} dI_p - \frac{\mu}{2} dv \quad [26]$$

$$dV_{g1} = -R_1 dI_p + dv \quad [27]$$

$$dV_{p2} = -\frac{\mu(R_1 - R_2) + (R_1 + R_2)}{2} dI_p + \frac{\mu}{2} dv \quad [28]$$

$$dV_{g2} = -R_2 dI_p \quad [29]$$

$$dV_0 = \frac{\mu(R_1 - R_2) + (R_1 + R_2)}{2} dI_p - \frac{\mu}{2} dv \quad [30]$$

Letting B stand for

$$\frac{\mu(R_1 - R_2) + (R_1 + R_2)}{2} \quad [31]$$

[30] can be rewritten as

$$dV_0 = B dI_p - \frac{\mu}{2} dv \quad [32]$$

At this stage, we can proceed as follows: if B = 0, the output voltage dV_0 is strictly proportional to the input voltage dv. The influence of dI_p, which is not a linear function of dv, is hidden by B. The SRPP circuit then behaves like a true linear circuit.

The condition B = 0 is always possible, in which case R_1 and R_2 can be linked in the following relationship:

$$R_2 = R_1 \frac{(\mu + 1)}{(\mu - 1)} \quad [33]$$

For this particular condition, the gain is:

$$G = \frac{dV_0}{dv} = -\frac{\mu}{2} \quad [34]$$

If $B \neq 0$, the influence of dI_p can no longer be hidden by B, and the SRPP circuit is no longer linear. It produces distortion, as does the classical circuit that I will now evaluate.

If we express $du_2 = \left(dV_{g2} + \frac{dV_{p2}}{\mu}\right)$ as a function of dI_p and dv, we have:

$$du_2 = -\frac{(\mu + 1)(R_1 + R_2)}{2\mu} dI_p + \frac{1}{2} dv \quad [35]$$

Letting $A = \frac{(\mu + 1)(R_1 + R_2)}{2\mu}$

and substituting [35] into [24], we obtain:

$$dI_p = f'\left(-A dI_p + \frac{1}{2} dv\right) + \frac{1}{2} f''\left(-A dI_p + \frac{1}{2} dv\right)^2 + \ldots \quad [36]$$

The last equation can be rewritten using a second-order Taylor's expansion for the triode characteristic and rearranging according to descending powers of dI_p:

$$dI_p^2 - dI_p\left[\frac{2(1 + f'A)}{f''A^2} + \frac{dv}{A}\right] + \left(\frac{f'}{f''} + \frac{dv}{4}\right)\frac{dv}{A^2} = 0 \quad [37]$$

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Reader Service #14

The solution for this second-order equation allows us to calculate dI_p as a function of dv and consequently to solve the entire set of equations, since we can express all the unknowns as functions of dv.

If we choose the only one of the two possible solutions of [37] for which $dI_p = 0$ when $dv = 0$, we obtain

$$dI_p = \frac{(1+f'A)}{f''A^2} + \frac{dv}{2A} - \frac{(1+f'A)}{f''A^2}\left[1+\frac{f''Adv}{(1+f'A)^2}\right]^{1/2} \quad [38]$$

We can express [38] in more detail if we use a second-order Taylor's expansion for the following expression

$$\left[1+\frac{f''Adv}{(1+f'A)^2}\right]^{1/2}$$

We then have:

$$\left[1+\frac{f''Adv}{(1+f'A)^2}\right]^{1/2} = 1 + \frac{f''Adv}{2(1+f'A)^2} - \frac{f''^2A^2dv^2}{8(1+f'A)^4} + \ldots \quad [39]$$

Substituting [39] into [38], we have:

$$dI_p = \frac{f'}{2(1+f'A)}dv + \frac{f''}{8(1+f'A)^3}dv^2 + \ldots \quad [40]$$

We can now calculate dV_0 by substituting [40] into [32]. We then have:

$$dV_0 = B\left[\frac{f'}{2(1+f'A)}dv + \frac{f''}{8(1+f'A)^3}dv^2 + \ldots\right] - \frac{\mu}{2}dv \quad [41]$$

Rearranging [41] according to increasing powers of dv gives:

$$dV_0 = \left[\frac{Bf'}{2(1+f'A)} - \frac{\mu}{2}\right]dv + \left[\frac{Bf''}{8(1+f'A)^3}\right]dv^2 + \ldots \quad [42]$$

Equation [42] shows that the output voltage dV_0 is not a linear function of dv. It is composed of one first-order term and one second-order term, due to the local curvature at the resting bias point of the triode characteristics. It allows us to calculate the gain and the first term of distortion of the SRPP circuit. The gain is:

$$G = \frac{dV_0}{dv} = \left[\frac{Bf'}{2(1+f'A)} - \frac{\mu}{2}\right] \quad [43]$$

For the first term of distortion, an input-voltage signal is necessary for calculation. Suppose we have the harmonic input-voltage signal:

$$dv = e = e_0\sin(\omega t) \quad [44]$$

then:

$$dv^2 = e_0^2\left[\frac{1}{2} - \frac{\cos(2\omega t)}{2}\right] \quad [45]$$

Substituting [44] and [45] into [42], gives:

$$dV_0 = \frac{Bf''}{16(1+f'A)^3}e_0^2 + \left[\frac{Bf'}{2(1+f'A)} - \frac{\mu}{2}\right]e_0\sin(\omega t) - \frac{Bf''}{16(1+f'A)^3}e_0^2\cos(2\omega t) + \ldots \quad [46]$$

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Reader Service #11

The equation [46] is the frequency response of the SRPP circuit with a harmonic input-voltage signal. This frequency response contains a constant term, a first-order term, and a second-order term. If we desire a more complete frequency response, we must do the same calculations as above, but using a higher-order Taylor's expansion for triode characteristics.

COMMENTS

From the results obtained in the theoretical analysis, it follows that the relationship $u_1 = u_2$ is the most important in explaining the SRPP behavior. It is this relationship that allows you to obtain the parameter B, which you can always set to zero. This relationship is typical of triode tubes and justifies their use in the SRPP circuit. It implies a strict matching of the two triodes.

The rule $R_1 = R_2$ usually given for a proper design of the SRPP circuit, is not correct and must be replaced by the rule

$$R_2 = R_1 \frac{(\mu + 1)}{(\mu - 1)}$$

The usual practice, which consists of decoupling R_1 using a high-value capacitor, is not justified. To do this is equivalent to setting R_1 to zero, in which case it is impossible to set B to zero. The gain is effectively higher, but it is obtained with distortion. The SRPP then behaves exactly as a classical circuit and has no particular interest.

When the SRPP is used with $B \neq 0$, a constant appears in the output-signal voltage that is proportional to the square of the input-signal amplitude. This situation could create some conflicts when coupling the output of the SRPP to the input of the next stage.

CONCLUSION

In this article, I have established that the performance of the SRPP circuit is governed by the values of the parameter B. If $B = 0$, the SRPP behaves like a true linear circuit, with no distortion. If $B \neq 0$, the SRPP behaves like a classical circuit producing distortion. Accordingly, we can conclude that the SRPP is of interest only if it is used when B is set to zero. ■

See following page for response. ➔

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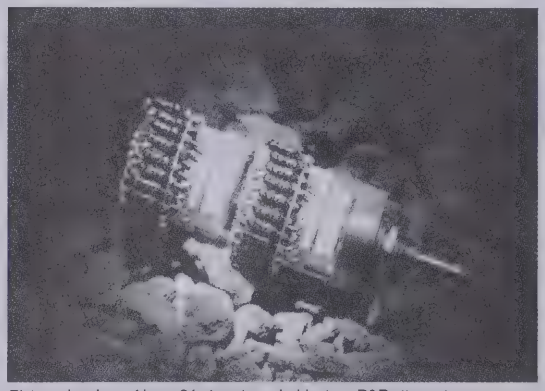

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Reader Service #86

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Reader Service #40

Mr. Touzelet's piece is very interesting, but contains a couple of flaws which, unfortunately, invalidate his argument. You can obtain his results with simple mathematical techniques.

The gain for the SRPP without cathode bypass is given by

$$A = \frac{\mu_1 r_{p2} + \mu_1 \mu_2 R_{k2}}{r_{p1} + r_{p2} + (\mu_1 + 1)R_{k1} + (\mu_2 + 1)R_{k2}} \quad [1]$$

If we assume that the two values are identical and that $I_{p1} = I_{p2}$, then

$$A = \frac{\mu}{2} \frac{r_p + \mu R_{k2}}{r_p + \frac{\mu + 1}{2} R_{k1} + \frac{\mu + 1}{2} R_{k2}} \quad [2]$$

If the stage is swinging a signal, the current swing will cause the value of r_p to change. If you denote the changed value of r_p at some arbitrary (non-zero) point on the signal, such as $r_p + \Delta r_p$, the gain at this point will be

$$A_1 = \frac{\mu}{2} \frac{r_p + \Delta r_p + \mu_2 R_{k2}}{r_p + \Delta r_p + \frac{\mu + 1}{2} R_{k1} + \frac{\mu + 1}{2} R_{k2}} \quad [3]$$

If gain at all points is identical, there is no distortion. This occurs also if Equation 2 equals Equation 3 at all points, or

$$\frac{\mu}{2} \frac{r_p + \mu_2 R_{k2}}{r_p + \frac{\mu + 1}{2} R_{k1} + \frac{\mu + 1}{2} R_{k2}} = \frac{r_p + \Delta r_p + \mu_2 R_{k2}}{r_p + \Delta r_p + \frac{\mu + 1}{2} R_{k1} + \frac{\mu + 1}{2} R_{k2}} \quad [4]$$

for all Δr_p.

This occurs when

$$\mu_2 R_{k2} = \frac{\mu + 1}{2} R_{k1} + \frac{\mu + 1}{2} R_{k2} \quad [5]$$

which can be rearranged as

$$\frac{R_{k2}}{R_{k1}} = \frac{\mu + 1}{\mu - 1}$$

which is Mr. Touzelet's result.

This result can occur only when $\mu_1 = \mu_2$ for all points as well, but the plate-to-cathode voltage of the two values are swung in opposite directions, and μ changes with plate-to-cathode voltage in all real-world values.

Even if you could build a value with absolutely constant μ, the result depends also on $\Delta r_{p1} = \Delta r_{p2}$, meaning $\Delta I_{p1} = \Delta I_{p2}$, therefore, the output current must equal zero, and the stage cannot be loaded.

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Reader Service #96

A Different Triode Power Amp

This circuit is a triple threat—unique, safe, and stable—for driving low-mu power triodes.

BY JOHN STEWART

Designers of audio power amplifiers have long recognized the benefits of using triodes as the final stage. However, some of the best of these tubes are difficult to drive. Others require large and dangerous high-voltage power supplies. Many need special interstage transformers. Some even need a DC power source to run a directly heated cathode.

The circuit I describe (*Fig. 1; Fig. 2* shows the power supply) overcomes all of these shortcomings. It uses readily available standard parts. You can probably find most of them in your junk box; otherwise, they are readily available commercially. Parts specifications are shown in *Table 1*.

For this circuit I wished to use power tubes that are widely available at low cost on the NOS market. (Many tubes built recently offshore have been found inadequate for one reason or another.) To demonstrate the principle I use here, I chose the 6080/6AS7G family.[1] However, you can apply these same concepts to several other low-mu triodes.

POSITIVE FEEDBACK

I use a form of bootstrapping or positive feedback here to overcome the extensive drive requirements of the low-mu triodes. If some purists object to this, I remind them that a similar fix appears in all the very famous and outstanding McIntosh amplifiers.[2] Also, Norman Crowhurst used the technique in his "Twin Coupled Amplifier" design.[3]

The ultralinear taps found on most output transformers, both old and new, provide the bootstrapping. It is applied to the ends of the driver-stage load resistors, so that the signal voltages at these points in the circuit are series aiding. The driver stage then does not need to provide the enormous drive signal normally required by a low-mu triode such as a 6080. There

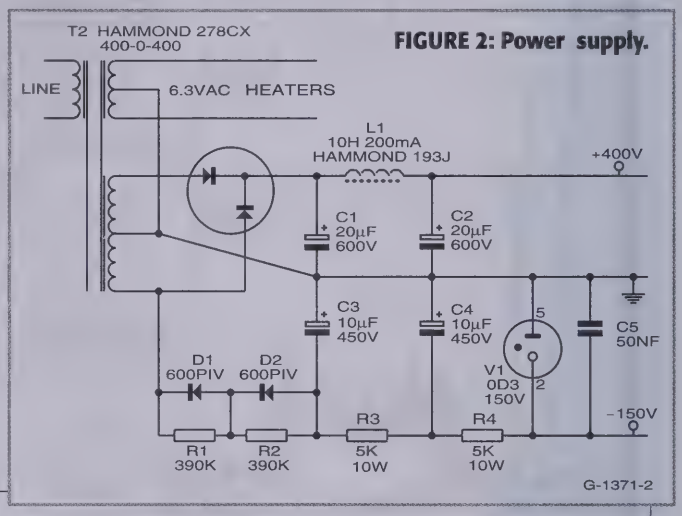

FIGURE 2: Power supply.

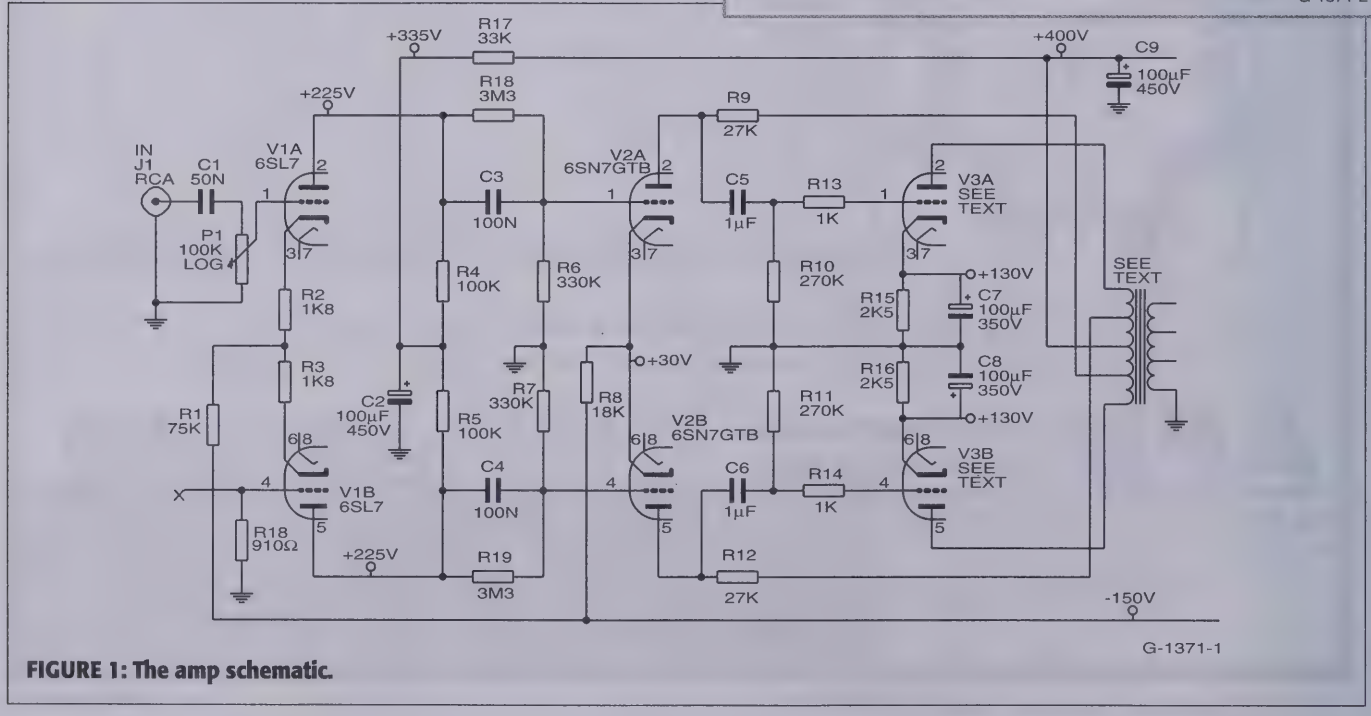

FIGURE 1: The amp schematic.

are similarities here to the McIntosh, but I've never seen this applied to triodes.

If you were to redraw the circuit with the output triodes side by side, it would take on the appearance of a multivibrator, and you might think instability would occur. This does not happen, however, since the gain of this part of the circuit is less than 1. The tap on the output transformer is at 43%, and this—when coupled to the 6080 with a mu of 2—produces a gain of 0.86, resulting in stability. If you have on hand an ultralinear transformer with 20% taps, it will allow you to use triodes with a mu of up to 4.5.

TABLE 1
PARTS SPECIFICATIONS

APPLICATION MAX. DISSIPATION	MU/E/I/BIAS	PWR TRANS	CHOKE	OUTPUT	BIAS R15 & R16
6AS7-G/6080 PP 26W total	2/250V/50MA/ 125V	272DX 1.5A fuse 600VCT/150MA 6.3V/4A & 5V/3A	156R 1.5H/200MA 56Ω	1650N 4300Ω	2.7k/25W
2X 6AS7-G6080 PPP 26W each	2/250V/50MA 125V	272JX 2.5A fuse 600VCT/250MA 6.3VCT/8A & 5VCT/4A	158S 1.5H/250MA 60Ω	H300429 2150Ω	2.7k/25W
2X 2A3/6A3/6B4G PP 15W each	4.2/300V/50MA 75V	270EX 1.5A fuse 550VCT/125MA 6.3V/4A & 5V/3A	156R 1.5H/200MA 56Ω	*1645 4300Ω	1.5k/10W
2X 300A/B PP 40W each	3.8/450V/80MA 75V	272JX 2.5A fuse 600VCT/250MA 6.3VCT/8A & 5VCT/4A	158S 1.5H/250MA 60Ω	*1650N 4300Ω	1.3k/10W
2x 45 PP 9W each	3.5/275V/36MA 56V	270EX 1.5A fuse 550VCT/125MA 6.3V/4A & 5V/3A	156M 3H/100MA 86Ω	*1608/ 8kΩ or 1609/ 10kΩ	1.6k/10W

*See circuit modification

TRANSFORMER CHOICE

For the development work, I had on hand output transformers with both 20% and 43% taps. The one with 20% taps is a special Hammond winding, which I acquired around 1960 but never used. Its performance in the circuit was adequate, but not nearly as good as the one with the 43% taps. (You could use it to advantage with output tubes such as the 2A3, the 45, the 300B, and perhaps some of the transmitting triodes.)

The transformer with the 43% taps is a Hammond 1650N, readily available through many vendors. It has a primary impedance of 4.3kΩ and is a good match for a single 6080 connected in push-pull.

Using a single 6080 with the Hammond 1650N and a power supply of only 350V, this circuit produced 10W of very clean audio. This is in sharp contrast to other topologies using expensive output tubes such as the 300B—complicated drive circuits both with and without transformers, and sometimes with dangerous high-voltage power supplies needed to wake up the output tube.

As you can see, the driving circuit is quite ordinary except for the connection to the output-transformer primary. It

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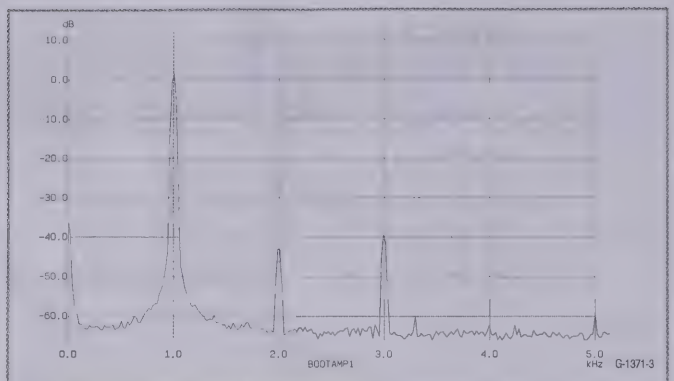

FIGURE 3: Pico-Scope measurements taken with no feedback, 10W output, and 400V power supply.

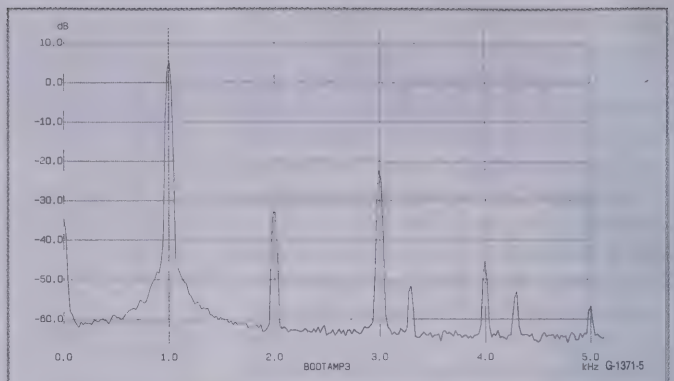

FIGURE 5: No feedback, 25W output, and 400V power supply.

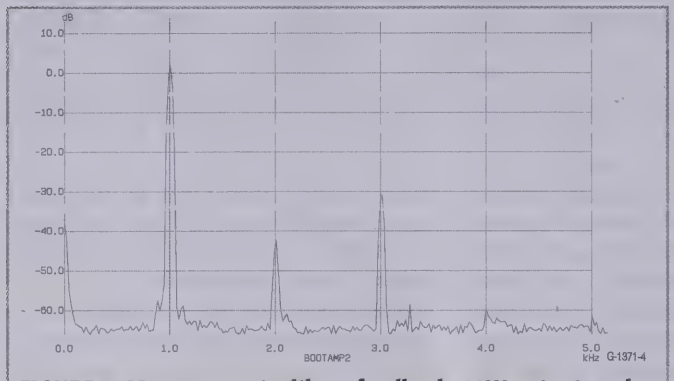

FIGURE 4: Measurement with no feedback, 10W output, and 300V power supply.

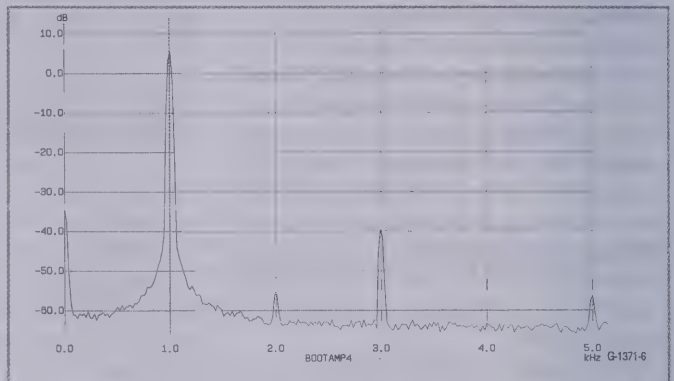

FIGURE 6: 13dB feedback, 25W output, and 400V power supply.

consists of only two double triodes. The choice of driver tubes has nothing whatever to do with what this or that tube might sound like. I based the selection on the ease with which I could implement component changes on the octal sockets. The primary objective here was to illustrate the drive-circuit principle.

MORE POWER

Since the development circuit was a success, I decided to go for more power. The final circuit uses the original driver, but has a pair of 6080s in the output stage. This required an output transformer with half the original primary impedance, and Hammond was able to provide one with a primary impedance of 2.15kΩ. It uses the same core as the 1650N, which is rated at 60W audio. The Hammond part number is H300429. With a power supply of 400V, this version produced an easy 30W of triode audio power.

In both versions of the amplifier, you must take care with the biasing of the

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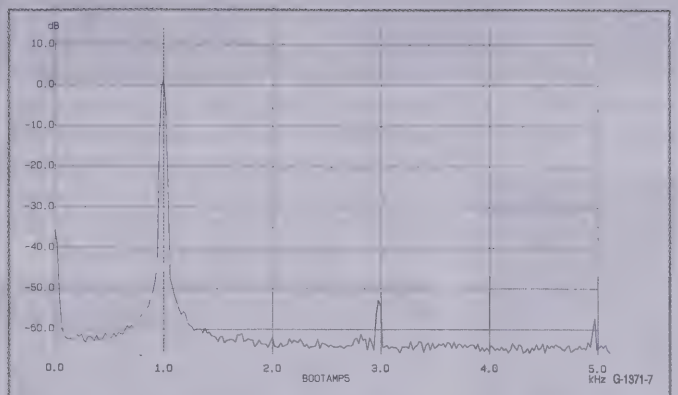


FIGURE 7: 13dB feedback, 10W output, and 400V power supply.

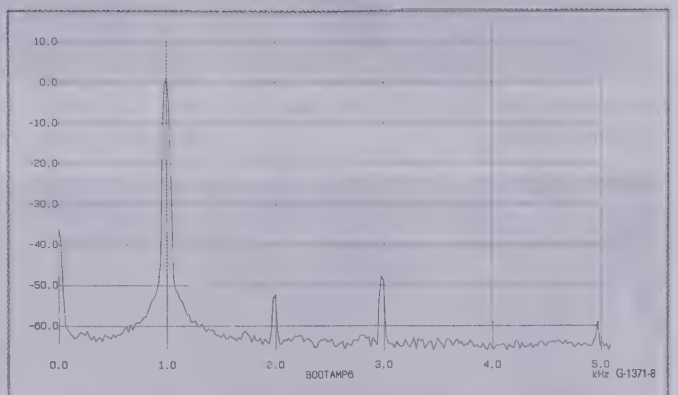


FIGURE 8: 13dB feedback, 10W output, and 300V power supply.

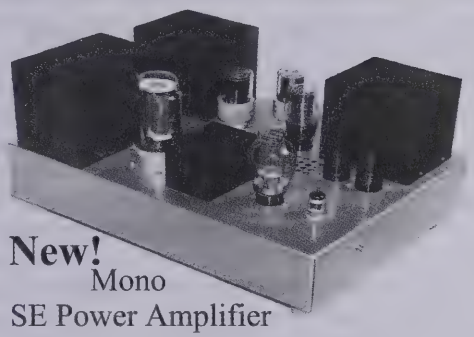
output tubes. Unlike most other output stages, each of these must have a separate cathode-biasing resistor. Otherwise, a condition of thermal instability not unlike that of power-junction transistors rapidly destroys the tube. Also, since fully one-third of the output-stage high-voltage power supply is dissipated in the biasing resistors, they will need good ventilation. In the development unit, they are under the chassis, but it will not be used for entertainment, and so does not need to run continuously.

The output-stage cathode resistors are rated at 25W. I had earlier tried 10W resistors, but found them inadequate for this application, since too much resistance change occurred as they heated up. The signal-input capacitor is calculated for a 3dB rolloff at 3.2Hz, but you can set it to anything you consider practical.

MEASUREMENTS

I obtained spectral test results using a PicoScope ADC100 (available from Pico Technology Ltd., Broadway House, 149-151 St Neots Rd., Hardwisk, Cambs, CB3 7QJ, England) connected to the printer port of a 486DX2/66 (*Figs. 3–8*). The ADC100 is a 12-bit converter with a predicted dynamic range of 72dB. When you use it in DOS mode, it manages about 70dB. My signal source for the test was an HP200CD audio oscillator.

For the measurements taken with 13dB feedback, I used a resistor of 4.7k. Why 13dB? Just a moderate feedback, since this circuit doesn't need much. I connected the feedback from the 8Ω tap of the output transformer to the 6SL7 grid opposite the input connection. If this causes oscillation, then you need to re-



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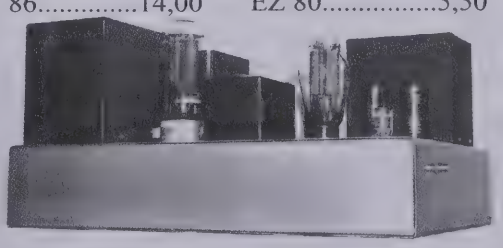

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verse the transformer secondary hookup.

The damping factor is 3 without feedback, but it rises to 15 with this feedback. Input sensitivity drops from 0.64V to 3.1V for 25W out.

The power supply uses an octal replacement rectifier available from New Sensor Corporation (20 Cooper Sq., New York, NY 10003, 212-529-0466, FAX 212-529-0486). The transformer and filter choke depend on which version of the amplifier you build. The single-6080 version could use a Hammond 272DX transformer and 156R choke. For the one using two 6080s, try the Hammond 272JX and 158S. These combinations will result in a high voltage of about 380. The 400V power supply I used is a bit on the high side. The 6080 dissipation ratings are exceeded.

The negative 150V supply uses a gas regulator, the 0D3/VR150. The small cap in parallel removes some of the noise produced by the 0D3. Don't try a large cap here, since at this position it often results in a very good relaxation oscillator.

MODIFICATIONS

Some improvements follow if you would like to push the circuit further.

First, rather than using cathode biasing, which wastes power provided by the DC supply, you could use a bias servo.[4,5] You could then reduce the high-voltage power supply to 270V.

Second, the gain of this version is somewhat low, so that when full-loop feedback is applied, the input drive signal requirement may be high. You could add another gain stage (with care) to the front end to restore sensitivity. Even McIntosh found this to be the case in its amplifier.❖

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3. Norman H. Crowhurst, "High Fidelity at Low Cost With Twin Coupled Amplifier," *Radio Electronics*, Nov. 1957; "Updating the R-E Twin Coupled Amplifier," *Radio Electronics*, June 1960; "High Power Twin Coupled Amplifier" *Radio Electronics* Oct. 1960; "Realistic Audio Engineering Philosophy," reprinted in *Audio Anthology*, Vol. 5."
4. Morgan Jones, *Valve Amplifiers*, p. 227."
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TUBE STRUCTURE

With reference to Matt Kamna's article, "300B on Test" (*GA* 4/98), the author wondered why his 300B had different THD and output. No, there is probably no dynamic-emission phenomenon. The I_a/U_a curves show clearly some typical design faults of certain types of tubes. One source (*Barkhausen Electron Tubes*: Vol 1, Fundamentals, Hirzel, Leipzig, 1928 [reprinted 1945], pp 103 ff.) attributes these to "island-effect" and "variability of the mu-factor."

If the grid wires of a tube are "thick" with respect to the grid-to-filament distance, there will occur a "shadowing" effect in the electric field near the cathode/heater, and the transconductance will vary otherwise than in accordance with Child's ⅔ power law. This is probably not the case with the 300B tubes, since they are rather old low-mu types, which means that their grids are just "loosely" wound with thin wire (no power dissipation required), and the heater-to-grid distance is rather large—low transconductance, but very linear.

On the other hand, if the active part of the heater is protruding out of the grid cage, this part will deliver plate current almost independently of grid control, but dependent on plate voltage. This is probably the case, as the curves seem to indicate. In other words, the tube will behave like a normal low-mu triode in parallel with a super-low-mu triode, and will therefore produce only low power with excessive distortion. Typically, such tubes show a "tail" in the characteristics, needing a higher-than-desirable bias for cutoff.

The higher the heater voltage, the longer the part of the heater outside of grid control will be able to emit plate current at a sufficently high plate voltage so that the electrons are "pulled around" the grid cage toward the plate. Lowering the heater voltage means a lower heater temperature, and therefore less emission from heater parts close to the supporting structure, but still enough to support normal operation.

Of course, shielding and not coating this part with oxides at all would suppress this effect completely. See the picture inside the back cover of *Glass Audio* 4/98: the mica spacer is very high above the system, and there is no shield to block electrons. Compare this to the AVVT tubes on page 70. They all have integrated shields!

Taking an 812-type construction and coating the heater with oxide will not give you a "good" 300B. The 812 has a thoriated heater, the emission of which is extremely sensitive to temperature changes; there will be *no* emission from parts close to the support. An oxide-coated heater, on the other hand, has a rather large range of working temperature, and will show this effect quite clearly.

Although reducing the heater voltage does work, it is definitely not the correct remedy. The builder should do his homework: do not coat the heater outside the grid cage or too close to it. Perhaps make the filament a bit shorter, so the cooling effect of the wire's suspension will be more pronounced, or use an appropriate shielding device, or both.

Diethelm T. Utzinger
Zug, Switzerland

Matt Kamna responds:

I would like to thank Mr. Utzinger for his wisdom and insight into 300B construction. His knowledge and background delve into areas on which you seldom find much information in today's magazines.

I went back to look at all my 300B samples, minus the Sovtek ones I sent back. The "active part of the heater" section does not protrude out of the "grid cage," which is exactly how my original Western Electric tubes were built. The original 300Bs do not have any grid shielding in the top of the envelope like the AVVTs and JJ300Bs.

I believe that if you're going to clone a tube, you should strive to get the details exactly like the original, which Westrex has done excellently. This is not to say that the tube can't work well, but it has a much better shot at working in more circuits, not to mention changing the sonic signature.

A good example of this is the popular and good-sounding RCA 6SN7GTB. For some reason, RCA chose to put the getter at the bottom of the tube instead of at the top, such as those of other manufacturers. This adds about 1pF of extra capacitance in the wrong place—the grid of one section to the plate of the other. In my cascaded gain-stage amp circuit, this turned a good-sounding amp into an 11kHz high-power oscillator!

This can be remedied by reversing section 1 and 2 in the circuit. If I had not first tested this at the bench, it would have cost me $350 in new tweeters. I'm very lucky not to have done tube testing that day!

For those die-hard audiophiles who read this magazine cover to cover, here's another tidbit. I recently tested the JJ Electronics 300Bs. One made 13.8W in my latest amplifier circuit! No, they're not very close to the original in many respects. They do look neat with their white ceramic bases, and were apparently made to be shown off, because the base is too large to fit either in a bayonet-style socket or possibly in some recessed socket applications.

CHILD'S LAW VARIATION

Two articles in *GA* 4/98 particularly aroused my interest, since I have spent much time in the last year studying the fundamentals of vacuum-tube physics with the goal of developing improved mathematical SPICE simulation models.

First of all, Don Jenkins' article ("Measurement of AC Plate Resistance," p. 18) was filled with valuable data and methods, but it bothered me that it could be read as suggesting that a "perfect" tube would have constant R_p and g_m. Certainly this would be an audiophile's dream amplifying device, but the physics of tubes shows that even a perfectly designed and built tube will show a variation, such that R_p rises and g_m falls, with decreasing current. This follows from Child's Law, which says that for a triode,

$$I_p = K\left(V_g + \frac{V_p}{\mu}\right)^{3/2} \qquad (1)$$

where K is a constant for any given tube, depending on the electrode spacing and size. Other symbols have their usual

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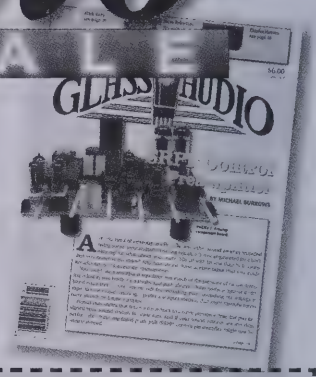

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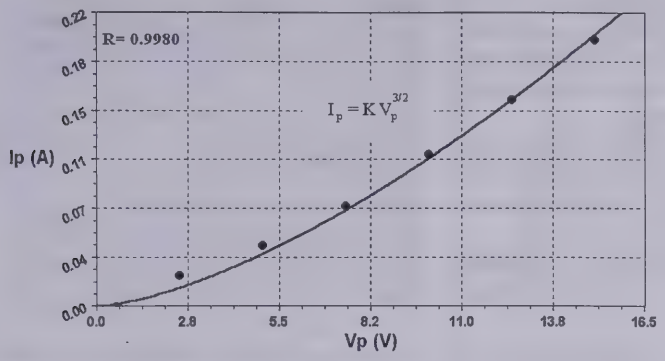

FIGURE 1: CLL applied to the GZ33 diode.

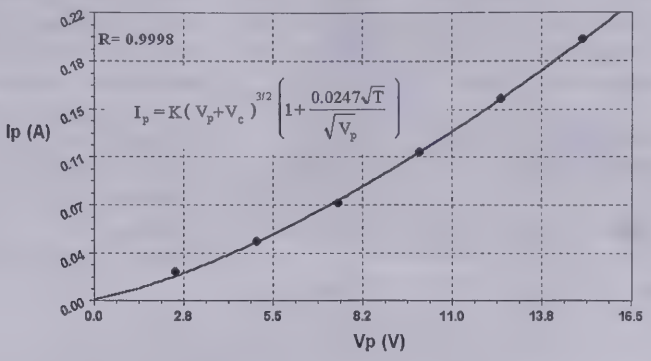

FIGURE 3: CLL adding the initial electron velocity and the contact potential applied to the GZ33 diode.

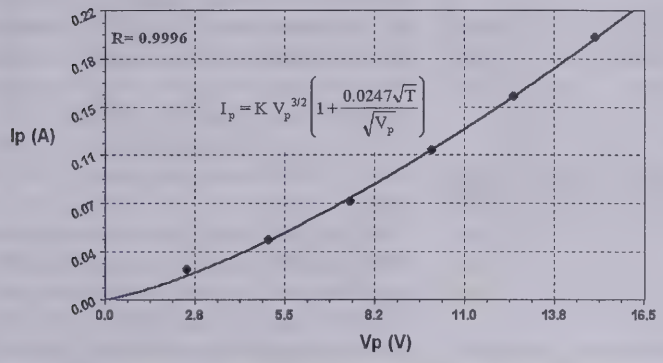

FIGURE 2: CLL adding the initial electron velocity applied to the GZ33 diode.

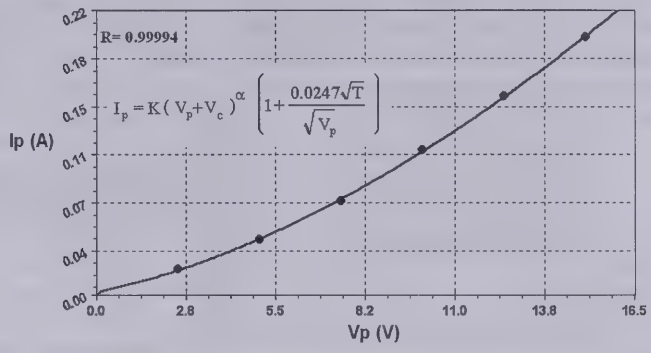

FIGURE 4: CLL adding the initial electron velocity, the contact potential, and variable capability to the exponent, applied to the GZ33 diode.

meanings. By definition, g_m is simply the derivative of I_p with respect to V_g. Taking this derivative and rearranging gives:

$$g_m = \frac{3}{2} K^{2/3} I^{1/3} \qquad (2)$$

and similarly for plate resistance, which is the derivative of V_p with respect to I_p. (The term "resistance" can lead to misinterpretation, since we tend to think of resistances as being constant, and may therefore suppose that the plate resistance "ought" to be constant.) This gives the formula:

$$r_p = \frac{2}{3} \frac{\mu}{K^{2/3} I^{1/3}} \qquad (3)$$

REFERENCES

1. Langmuir, I., "The Effect of Space Charge and Initial Velocities on the Potential Distribution and Thermionic Current between Parallel Plane Electrodes," *Physics Review*, Vol. 21 (April 1923)
2. Mitchell, T., *The Audio Designer's Tube Register*, Vol. 1 (available from OCSL).
3. Dow, W. G., *Fundamentals of Engineering Electronics*, John Wiley, 1937.

You can find both of these formulas in the classic texts.

Then, Stefano Perugini's article ("Vacuum Diode Models & PSpice Simulations," p. 38) was very stimulating. This is the first detailed study I have seen of diode behavior. Diodes are interesting because the physics of their operation is much simpler than for triodes. Indeed, the standard analysis of a triode first develops an "equivalent diode" and then proceeds from there.

Mr. Perugini's graphs show very clearly the limitations of Child's Law, which is in fact only an approximation. In particular, it assumes that all electrons leave the cathode with zero velocity. In fact, the electrons within most of the cathode have a distribution of energy (and hence velocity) that depends on temperature, and so do those that manage to escape. The problem of initial electron velocity was comprehensively studied by Langmuir,[1] giving rise to an improved approximation:

$$I_p = K \times V_p^{3/2}\left(1+\frac{0.0247\sqrt{T}}{\sqrt{V_p}}\right) \qquad (4)$$

where the new variable T is the temperature of the cathode, typically 1000–1100°K (or around 800°C) for an oxide-coated cathode. This results in substantially higher currents (up to 40%) at lower plate voltages, and noticeably higher values even at high currents. For example, when V_p is 30V, a high value for a diode, the extra factor adds about 14%. This equation accounts rather precisely for the higher currents shown at the left of the graphs, and hence the apparent lower value of the exponent. It also explains why current increases with heater voltage, which Child's Law and its underlying explanation leave as a mystery.

Even this formula (equation 4) becomes incorrect at low plate voltages, because the escaping electrons actually form a "virtual cathode" in front of the true cathode, with a slight negative potential (around –0.5V at 1mA). This increases the effective plate voltage and reduces the effective distance of the plate, both of which have the effect of increasing the current. A diode or triode with 0V on the plate still passes measurable current; for example, Mitchell[2] shows 0.32mA for a 6DJ8 under these condi-

tions. The mathematics of this situation is, however, rather complicated. The best treatment of it in (relatively) accessible literature is in Dow.[3]

John Harper
Valbonne, France

Stefano Perugini responds:

I agree with Mr. Harper's point of view. In tube modeling, a subtle error has spread regarding the Child-Langmuir Law (CLL):

$$I_p = K_d V_p^{\frac{3}{2}} \quad (5)$$

I have shown in a visual manner (*GA* 4/98) that CLL is already incorrect for vacuum diodes; unfortunately, in classic theory the triode is seen as a diode subject to the following law:

$$I_p = K_t V_{cum}^{\frac{3}{2}} \quad (6)$$

where:

$$V_{cum} = V_g + \frac{V_p}{\mu} \quad (7)$$

is the cumulative potential.

Therefore, if equation 5 yields a correlation coefficient (R) close to 0.9990 by applying a nonlinear regression method, the situation becomes more uncertain when equation (6) is used for triode curve fitting. You can expect values close to 0.800 for R for signal triodes, but lesser ones for power triodes, with errors concentrated where nonlinear effects are more evident (and more interesting).

Vacuum diodes are simple to model, and therefore their behavior can help in understanding the physics of more complex devices such as triodes and pentodes.

Figure 1 is the result of curve-fitting with nonlinear regression applied to the GZ33 diode; the error is mainly concentrated in the low-voltage area.

Figure 2 refers to the improved approximation of CLL. Results are consistent with Mr. Harper's remarks.

Figure 3 adds the cumulative potential to the previous model.

Finally, *Fig. 4* adds a variable capability to the exponent: now the correlation coefficient is greater than 0.9999, and a best fit results in the low-voltage area.

For a better result with the conservative approach (i.e., based on physical laws), we probably must know the influence of diode geometry on the potential distribution.

FOLLOWER FOIBLES

Ignacio Vilá's article in *GA* 4/98, "The Beta Follower Amplifier," is another interesting twist on the mu-follower concept. Vive la difference.

I believe I can clear up the mystery he mentions as to why C3 in his Figure 1 (the cathode capacitor in the bottom triode) has an audible effect even though "it affects neither the gain nor the PSRR." The reason may be that C3 actually has a measurable effect on Z_{out} and the power-supply rejection ratio (PSRR).

This can be understood by examining the audio-frequency model of the beta follower (*Fig. 5*). In the figure, rp_B, gm_B,

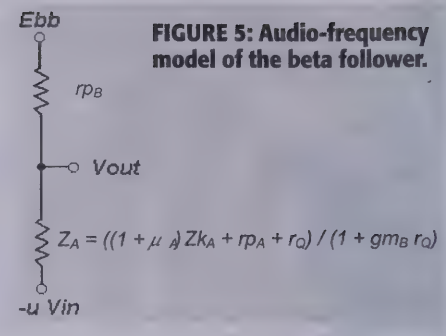

FIGURE 5: Audio-frequency model of the beta follower.

rp_A, and μ_A are the standard triode parameters; r_Q is the total resistance of the LM394 circuit (Q1, R1, C2, and R3), and Zk_A is the impedance of the parallel combination of the cathode components R2 and C3 of the bottom triode V_{2A}. Note that Zk_A (and therefore C3) contributes to the value of Z_A. The following equations hold:

$$\text{Gain} = -\mu V_{in} \times rp_B / (Z_A + rp_B)$$
$$Z_{out} = Z_A \times rp_B / (Z_A + rp_B)$$
$$\text{PSRR} = Z_A / (Z_A + rp_B)$$

In Mr. Vilá's circuit, as in all good beta or mu followers, Z_A is a lot smaller than rp_B. This condition has positive implications for gain, Z_{out}, and PSRR, since the following approximations hold:

$$\text{Gain} \approx -\mu V_{in}$$
$$Z_{out} \approx Z_A$$
$$\text{PSRR} \approx Z_A / rp_B$$

As can be seen, Z_A affects both Z_{out} and PSRR, but not gain, and Z_A is in turn affected by C3.

On a different note, I have some concern about the repeatability of the tran-

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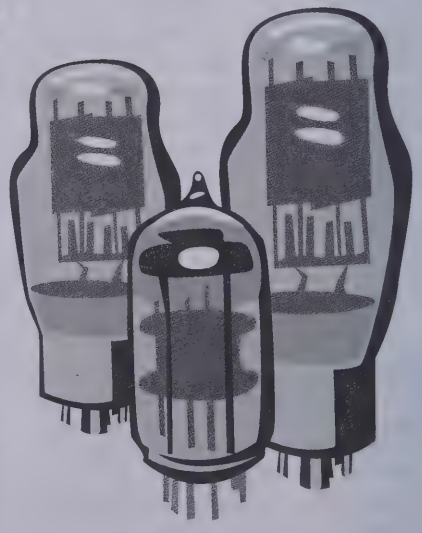

Reader Service #77

sistor circuits that Mr. Vilá uses. Consider the DC portion of his Figure 1 circuit, which consists of Q1, R1, and R3. For the component values shown, the operation of this circuit is very dependent on the beta of the transistor, which varies with temperature and from device to device. This means that someone else building Mr. Vilá's circuits may find it necessary to use values of R1 or R3 different from those published. Within a manufacturing lot of these transistors, performance may be repeatable, but this is no guarantee that the next lot purchased by someone else will perform in the same manner.

Let me demonstrate what I mean by beta dependency. Assume that Q1 passes 7mA, and that you use the recommended LM394, rather than the 2N2222 shown in Figure 1. The manufacturer says that Q1's β can be as small as 300 at 1mA and 25°C. A typical value of 700 is given, but the maximum is not specified. It is not unreasonable to assume a maximum β of 1000. For a β of 300, 7mA/300 flows through R1 (125k), producing a voltage drop of 2.9V. But for a β of 1000, 7mA/1000 flows through R1, yielding a drop of only .88V—more than a 2V difference! Different transistors with different betas will yield significantly different grid–cathode voltages, and therefore triode biases.

One way to avoid β dependency in a design is to choose the base resistor to be no more than one-tenth the product of β and the emitter resistor. This ensures that almost all the voltage drop across the circuit occurs across the emitter resistor rather than the base resistor, the drop across which is proportional to the beta-dependent base current. Mr. Vilá has not done this, and for good reason: it is very difficult to follow this stricture while choosing a high value of R3 (thus maintaining high Z) and still achieving a reasonable combination of plate current and grid-cathode voltage. Consider the following example.

Suppose you wish to source 7mA across a total drop of 4V. The base-emitter transistor junction provides .65V of that drop, leaving 3.35V across the base and emitter resistors. Since the base resistor is less than one tenth of β times the emitter resistor, almost all of that 3.35V falls across the emitter resistor. 3.35V/7mA = 480Ω, the emitter resistor value. If β = 300, the base resistor must be less than 14.4kΩ (one tenth of beta times the emitter resistor value), hardly a high-impedance result.

There is a solution that avoids capacitors and uses a few transistors and resis-

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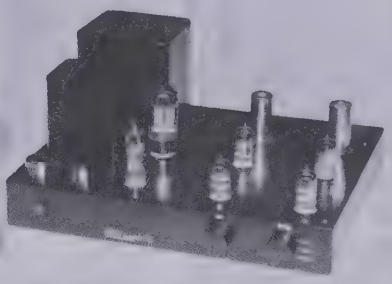

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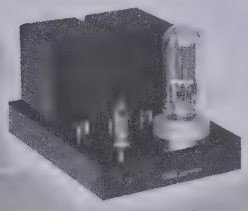

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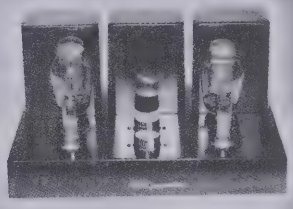

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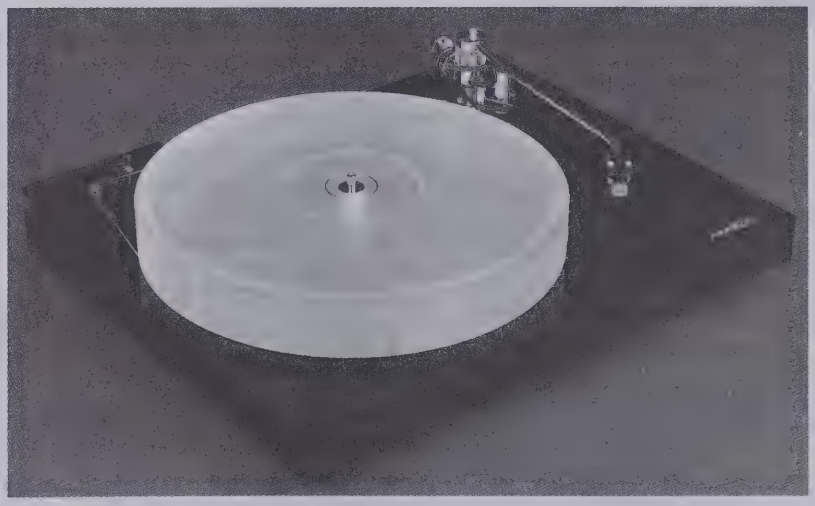

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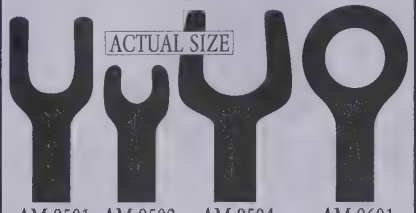

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Reader Service #38

tors that you can pick up in Radio Shack. As a bonus, you can also use one of the resistors to draw extra current from the top tube as Mr. Vilá does (the "asymmetrical" mu/beta follower). But I'll reserve this solution for an Audio Aid.

Chris Paul
Bayport, NY

Ignacio Vilá responds:

In response to Christopher Paul's letter, I first wish to mention that I have followed his principles about means to improve the PSRR. If I had not learned from his articles in *TAA*, it would have been impossible for me to build the preamp. I consider it a variation, good or bad, of his mu-follower. It is for this reason that I called it "beta-follower."

As to the role of C3, the preamp works fine and with a good sound without it. Mr. Paul is right in that it affects both the gain and the PSRR, but it decreases the output impedance in a magnitude that is less than 10%, and with respect to the PSRR, the improvement is approximately 10%. Knowing this result in advance of the actual audio tests, I doubt that the improvement could have been subjective.

Without any doubt, there is a connection between the base resistor and the beta of the transistor. It is for this reason that I indicated the beta value used in the preamp. But if in the linear stage you use a transistor with a beta of 1000, the current will be 5.2mA, whereas before it was 4.6mA. Using a transistor with a beta value of 500, the current will be 4.1mA. In all three cases, it will work correctly. What you cannot do is use any transistor without knowing its beta range, such as having any old value from 200 to 1000. There is always the solution of installing a pot in place of the base resistor.

ANSWERS FROM DOWN UNDER

I have three questions for Mark Kelly about the preamp of Fig. 1 in his article, "The Search for Linearity, Part 3" (*GA* 6/97, p. 42).

First, can I replace the 5687 with one 6BL7GT (or one 6BX7)? Second, is it possible to improve common-mode rejection, as in Figs. 10a and 10b of Part 2 of his article? Third, can I use the positive half of the balanced circuit as the single-ended output?

Hugo Sottomayor
hugo sottomayor@yahoo.com

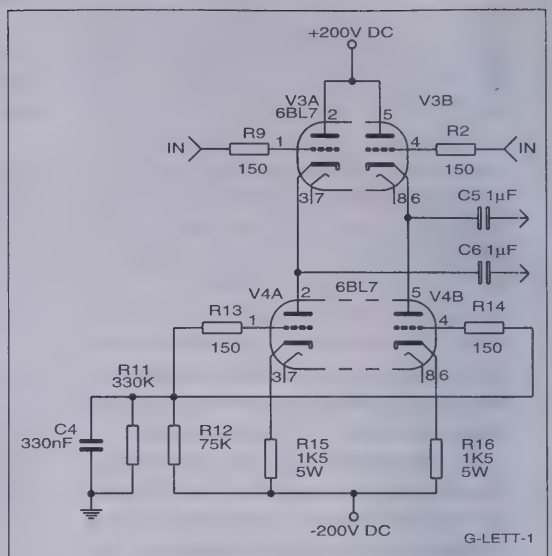

FIGURE 6: Tube substitution circuit.

Mark Kelly responds:

Of the two types mentioned, I would use the 6BL7, since it has a mu of 15 as against the 6BX7's mu of 10, and the higher mu will give better linearity as a CF. If you use both plates of the 6BL7 (e.g., using one half for each phase of a balanced output), the permissible plate dissipation is 6W per side, and 200V at 30mA

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seems to be an appropriate point. You then need to sink the 30mA in an active load, and another 6BL7 would seem the best choice.

The higher the cathode resistance on the loading 6BL7, the higher the cathode impedance on the CF (the benefits of which are outlined in the original article), but too high a value will limit the output swing available. A B– of –200V and an R_k of 1.5k should be a reasonable compromise, giving an effective cathode impedance of about 25k. The bias needs to be about –8V, and the 1.5k resistor will drop 45V, so the cathode of the lower valve will be at –155V, and the grid at about –163V. The circuit then becomes as shown in *Fig. 6*.

This circuit will have a Z_{out} of around 150Ω, and should be able to swing more than 100V RMS across any load above 5k, or 20mA into any load between 600Ω and 5k. A balanced pair would provide more than 200V RMS into 10k (that's greater than a 4W output).

The CMRR "improvements" in Figs. 10a and 10b refer to the Schmitt phase-splitter circuit, not the cathode follower, and in any case I have abandoned using them in favor of a stiffer constant-current source.

Finally, yes, it is all right to use one-half of a balanced circuit as a single-ended output, but you then lose all the advantages of balanced circuitry other than the constant power-supply drain, and if you're using constant-current sources, this is something of a moot point anyway. My preference in this situation would be to reconfigure the first stage as a differential amp.

CASCODE & SE AMPS

I read with considerable interest Bill Chater's article, "Cascode Power Amplifier Circuits (Part 1)," in *GA* 5/98. However, the author claims that the output impedance of his amplifier is 0.6Ω, while the cascode connection of the output stage is inherently extremely high. Look at the transfer characteristic in Figure 17. The operating range is above the "knee," and looks much like that of a 6L6 beam tetrode, except that the "knee" plate voltage is much higher in Figure 17. I suspect that Figure 17 is correct, while the low output impedance quoted is incorrect.

I have my own ideas about the grid-current problem. It is indeed a problem, and the solution is to "retread the grid current." Suppose the output tubes are driven into grid current; if the drivers are cathode followers, the grid current appears at the plates of these drivers. If these plates are tied to the output-tube plates, the output transformer sees $I_p + I_g$, and all is well. These cathode followers must operate in a constant-current

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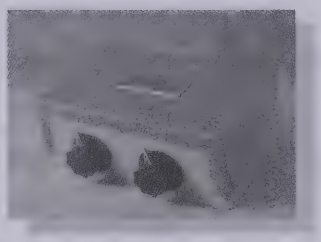

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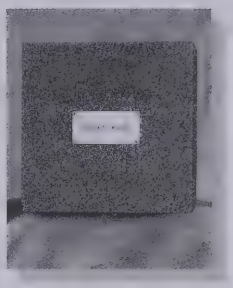

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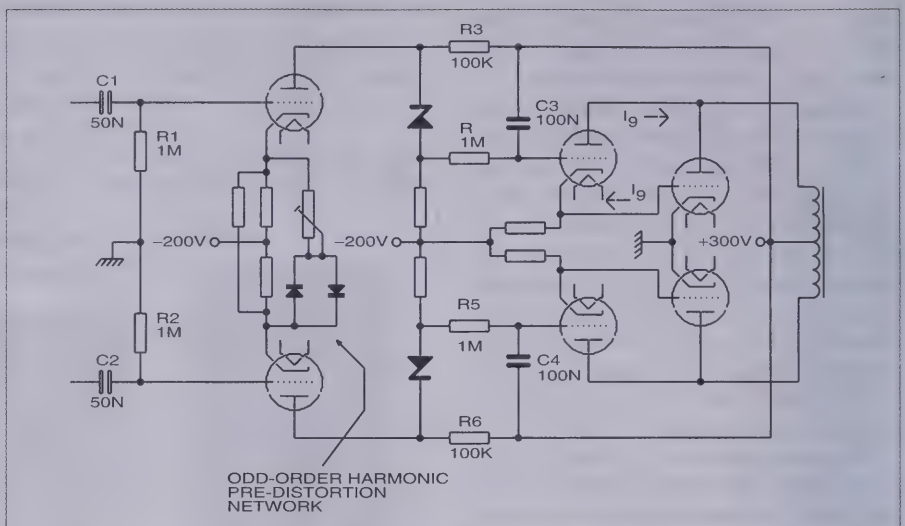

FIGURE 7: Reader Rhodese's remedy for dealing with distortion.

mode, and that is easily arranged.

Recently, I obtained some Sylvania 6B4-G tubes that have indirectly heated cathodes. The cathode appears to be tied internally to the mid-point of the heater, so you can use this tube in place of the old-style 6B4-G of the early 30s. This tube should make a wonderful sound with its low output impedance. I will not use the cascode connection, but grid-current re-treading, instead.

Also, in the same issue appears Larry Lisle's article on cancelling harmonic distortion (p. 30). This idea has merit, but I do not believe the circuit works as shown, because these tubes are AC-coupled. Aside from the low-frequency phase shift, there is a greater problem unless you are amplifying a pure sine wave, which, as you know, is a far cry from musical sound. Music is a complex waveform, whose positive and negative peaks may be quite different. The only constant element is the lack of a DC offset over long time intervals.

If there is a strong positive-going impulse versus a strong negative-going impulse, the signal swing of the first tube does not explore the same portion of the tubes's transfer characteristic in each case, and the harmonic-distortion cancellation fails. This is why DC-coupling is used for video.

What would work is to directly couple the stage intended to predistort the signal with the power stage whose harmonic distortion is to be reduced. I would AC-couple into the predistortion stage a push-pull version of the signal, use cathode-to-cathode degeneration, shunt that cathode-to-cathode resistance with a pair of small-signal diodes—connected as in *Fig. 7*—and adjust the amount of distortion they produce with a series resistance. These tubes would be direct-coupled to cathode followers that in turn drive the output pair. While it is a nuisance to provide the large negative voltage supply, it is well worth it.

I believe the true course to hi fi lies not in reducing harmonic distortion, but in suppressing intermodulation products. Music is what we wish to hear, not sine waves. Music contains at any instant multiple frequencies that make the waveform complex, yet beautiful to hear. A few more true harmonics make little difference, but IM generates new frequency components the ear is displeased to hear. IM products result from nonlinearity, the second harmonic of a first frequency beats with the fundamental of a second frequency, and some of these beats fall within the audible range of frequencies. IM distortion and low output impedance are what really count, plus, of course, low hum and noise levels.

Charlie Rhodese
Upper Marlboro, MD

Bill Chater responds:

Reader Rhodese has said he agrees with my article on one point, but disagrees with another. I am afraid I must reply in a similar way: I agree with him on one point, but not on the other.

He is correct in saying that the output stage has a very high output impedance, as demonstrated in the curves of Fig. 17. In the text I

SAY YOU SAW IT IN *Glass Audio!*

have pointed out that the tubes' equivalent plate resistance is 5.7kΩ. When the paralleled resistances of two such tubes are reflected to the transformer secondary, it looks like 11.5Ω, still a high number.

We disagree about the output resistance of the amplifier. It is, as stated, close to 0.6Ω. A quick way to verify this empirically is simply to apply the feedback factor of 20 to the above 11.5Ω, resulting in 0.575Ω. This is in fact very close to what I measure. A more complete explanation of the analysis of an amplifier's output resistance is found in the text of Part 2 of the article in *GA* 6/98.

Larry Lisle responds:

Mr. Rhodese raises a number of interesting points. The circuits I described in my article do cancel second-harmonic distortion and will also reduce intermodulation distortion substantially, as tested by both the SMPTE and CCIF methods. (See: Tremaine, *Audio Cyclopedia, Second Ed.*, Chapter 23 for methodology.)

This works because at the second-harmonic null, the transfer curve becomes very linear as long as triodes and good transformers are used and operated conservatively. Of course these tests are with sine waves, but if an amplifier won't reproduce a sine wave, it certainly won't reproduce music. As he mentioned, with music you might have a strong positive-going impulse versus a strong negative-going one. If the transfer curve is linear, the reproduction should be accurate.

He is correct in pointing out that phase shift can reduce the effect of harmonic cancellation at extremely high or low frequencies. This isn't a fault of harmonic cancellation, but rather a problem of amplifier design. All designs are compromises. To illustrate the principle of second-harmonic cancellation, I chose designs that would give very good reproduction with simplicity and clarity.

The most important test of music reproduction, however, is how the amplifier sounds. You can hear a difference when the second harmonic is nulled. Personally, I like the sound with classical music or contemporary jazz. Another listener may not like the sound at all, or may prefer that the harmonics are only partially cancelled, but that's why audio is an art as well as a science.

Variable second-harmonic cancellation is a tool, and like other tools it may or may not be appropriate or useful in a particular situation. It's easy to try, though!

The circuit Mr. Rhodese included (*Fig. 7*) looks most interesting. Perhaps he should consider writing an article to explain it in detail. ❖

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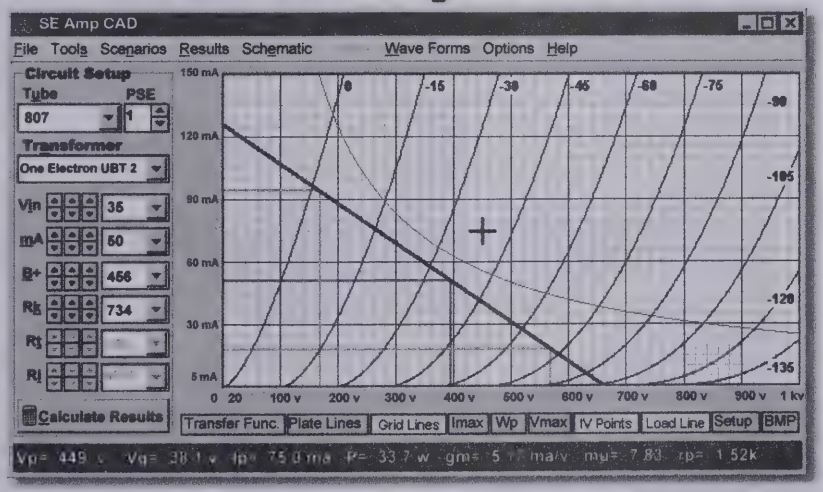
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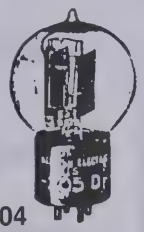

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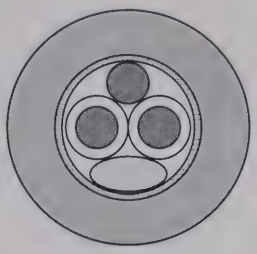

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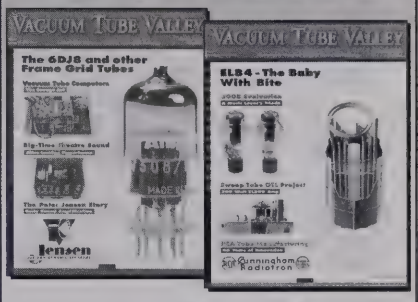

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ELECTRON FLOW

In a book by John D. Constance (*Electrical Engineering for Professional Engineers' Examinations*, 1959, McGraw-Hill Book Company, Inc.), there is a chapter on Electronic Tubes and Circuits, and one of its paragraphs stated "Although there is an electron flow from the filament to the plate, there is a current flow from the plate to the filament as measured by an ammeter." It goes on to say: "This is due to the fact that an ammeter shows the direction in which the positive charge of electricity flows. And since electrons are negative, their direction of flow is not registered by an ammeter."

This just about blew my mind! Please help. For years I have worked with all kinds of rectifiers in the related field of motion-picture projection. I have seen physical evidence between two carbon rods where the negative 7/16 inch carbon rod and the 13.6 MM positive rod shows a characteristic cratering on the positive rod and penciling down at the tip of the negative rod. We have electron flow from the negative rod across an air gap of about ½" to the positive rod where most of the light and heat is emitted. This is why the positive rod on a DC carbon arc is made larger. To me this is proof that the electron flow is from the direction of the negative rod to the positive rod.

I do not understand how you can have electron flow in one direction and current flow in the opposite direction. I have always understood it as being the electron flow of current. According to the book could it be held analogous to say that a school of fish representing the electrons are swimming against the current of a river?

I remember touching on the subject of transistor theory where you have electron flow in a series of holes which are positive in respect to the electron which have a negative charge. Could it be this that the book I am reading is referring to.

William Cooney
Norton, MA

Gary Galo responds:

Mr. Cooney has reopened a can of worms I stepped into back in 1989 when I reviewed the late Norman Crowhurst's *Basic Electronics Course* (second edition, Tab Books, 1987) in *The Audio Amateur* ("*Ask TAA*," 4/89). Mr. Crowhurst was an author I greatly respected and his death was a loss for all electronics hobbyists.

I criticized his book for getting "off on the wrong foot by illustrating conventional current flow on the very first page." Crowhurst illustrated with batteries how current produces a magnetic field. The arrows in his drawing show current flow from the positive to the negative terminals of the batteries. Yet, in his chapters on tubes he contradicted himself, stating "Electrons emitted by the heated negative electrode, called the filament or cathode, are attracted by a positive voltage applied to the other electrode, called the plate or anode; thus current flows in this direction."

Later, in his discussions of rectifier circuits, Crowhurst returned to conventional current flow with arrows pointing from positive to negative, or from anode to cathode. What he actually illustrated was movement within the diode, but that doesn't show the direction of

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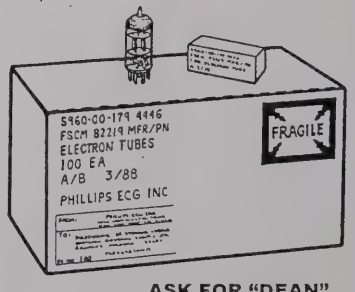

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electron movement in the circuit. Such contradictory information is likely to confuse anyone, and is the root of Mr. Cooney's question.

Based on our knowledge of the atom, electricity is the flow, or movement, of electrons in a conductor, from negative to positive. We now know that the older view of "conventional current flow" from positive to negative is incorrect, though electrical engineering still teaches the older theory because it is an established, deeply entrenched "convention."

Many engineers tell you that it doesn't really matter which way the current flows. I disagree. It is, of course, true that thousands of highly-talented circuit designers have been, and continue to be, taught the old way. Their positive-to-negative orientation doesn't prevent them from designing complex and highly successful circuits. But I believe that a correct understanding of how electron devices really operate, whether vacuum tube or solid state, can be best achieved by discarding the older theory in favor of electron flow from negative to positive. Once we accept the modern explanation, "current flow," "electron flow," and "electron current flow" become synonymous.

Rather than state more of my views on this subject, I refer you to respected authors in the electronics field.

From the references you'll note that many electrical engineers have perpetuated, and continue to perpetuate, an incorrect theory of current flow. I believe that it is difficult to understand how electron devices really operate using the antiquated convention. In particular, I find it impossible to explain the operation of the vacuum tube in terms of conventional current flow. Mr. Crowhurst probably agreed with me on this point, since his explanation of the vacuum tube was based on electron flow. We must at least be consistent in our explanations. Changing the direction of current flow, depending on which electron device is being explained, is a definite contradiction—one which is likely to leave the student more than a little confused.

A few comments about hole movement are in order. As far as scientists have been able to determine, the holes do not actually move in the physical sense of movement. Given that a hole is actually an area where an electron deficiency exists, the relationship between electron movement and hole movement can be viewed much like Chinese Checkers. If you accept Bleaney and Bleaney's statement that positive ions are fixed, then this analogy can also be applied to the movement of positive ions in metallic conductors, as well.

Imagine a row of atoms in which the electrons are in the majority, but at the end of the row is an atom where an electron deficiency exists, leaving a hole or net positive charge. In our Chinese Checkers analogy, the electrons are the marbles and the hole is, well, the hole! The last electron (marble) moves into this hole, leaving a hole in its place. Then, the second to the last electron moves into the newly created hole, leaving another hole in its place, and so on. As you can see, the positive charges never physically move, although there is an apparent transfer of positive charge in the direction opposite to the electron movement.

Some electrical engineers object to the word "flow" used in connection with electric current. If you accept the fact that the movement of electric current is the movement of electrons, then the term "flow" is entirely appropriate, since we are describing particles which are actually moving through a conductor, from one atom to the next. Several of the books cited use the expression "current flow," and I have no problem with it.

"Conventions" are always subject to change. For a substantial portion of Earth's history the alleged flatness of our planet was an accepted convention. The notion that our flat planet was the center of the solar system was another accepted convention. Fortunately, when hard evidence to the contrary convinced even the most die-hard skeptics, those conventions were discarded in favor of a more accurate view of Earth as a round body which, along with at least eight other planets, revolves around the Sun. In a way, this subject also reminds me of the arguments surrounding conversion to the metric system. We know it is a vastly superior system to what we continue to use in the United States, but we refuse to change because our conventional system is so deeply imbedded in every area of technology that the conversion would cost billions of dollars and untold inconvenience.

From the writings of the electrical engineers I've included (see "References"), it is obvious that there should be no debate on the subject of "current versus electron flow." Current flow and electron flow are the same and certainly are not opposed to one another, as it was once believed. I see no sense whatsoever for

REFERENCES

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Reader Service #83

perpetuating the errors of the past, especially when those explanations lead to misunderstandings and contradictions.

TUBE FUNCTION

Does anyone have data on the AZ31? I have many of these purchased at flea markets.

Darsana@hotmail.com

Charles Hansen responds:

According to the Mullard valve code chart, the AZ31 decodes as follows:
A = 4V heater
Z = full-wave rectifier
3 = octal base
1 = sequence number

With an internet search on AZ31, Yahoo! and HotBot report that the tube was used in the 1947 Ekco A52 short-wave receiver (British), and the 1953 Philips BX321A/50 table radio (Netherlands).

A FORMIDABLE PROJECT

I am attempting to convert an early 1950s super heterodyne monaural receiver into a two-channel stereo direct-conversion receiver. I have purchased a small toroid plate and filament transformer. Trouble is, the amperage is far below the needs of the tubes. How might I proceed to boost amperage? Is the inclusion of either a combined NPN and PNP emitter follower or a lively pair of high-power audio op amps an applicable path to pursue?

I also wish to allow the single nine-pin miniature socket to house a suitable pentode for the error amp in a voltage regulator, with the voltage reference tube to be the OC2 and the pass element most likely to be a 500V rated P-channel power MOSFET. In *The Art of Linear Electronics*, Mr. John Linsley Hood writes that for an error amplifier to be assigned to a solid-state pass element, three requirements must be present: 1. low output impedance, i.e., low plate output impedance. 2. high gain output; and 3. very stable operating behavior. Am I in the right "ball park" considering the following five: 7701, 6JQ6, 9LA6, 6KY8, and 6CS7?

I am also seeking to try another power output tube pair—a horizontal sweep tube pair that when operated as triodes each have a plate resistance of three digits, and low enough to work with an input impedance of 149Ω. Or, does three-digit plate resistance occur only with the few twin triode octagonals?

R. Sumner
Washington, DC

Charles Hansen responds

Whew! Converting a monaural receiver to stereo FM is not exactly my area of expertise. This is a formidable project even for an expert. There is no way to get more current from a transformer than it is rated to deliver. That would be like trying to get 30 amps from a 20 amp wall outlet. If you "put a penny in the fuse box" all you get is a fire.

In addition to the three requirements you mentioned, you cannot exceed any of the maximum ratings of the pass element. Not voltage, current, power dissipation or, in the case of bipolar transistors, the safe operating/second breakdown area. I really don't know enough about the design requirements for a tube reference circuit whether your tube choices are good ones or not. If you have them on hand, I guess the best course of action is to first try them in a breadboard with a dummy load. Stability must be addressed in the real-world application, of course. ❖

HOW TO CONTACT US

Glass Audio encourages reader feedback in the form of letters, queries, and comments. Send your correspondence to:

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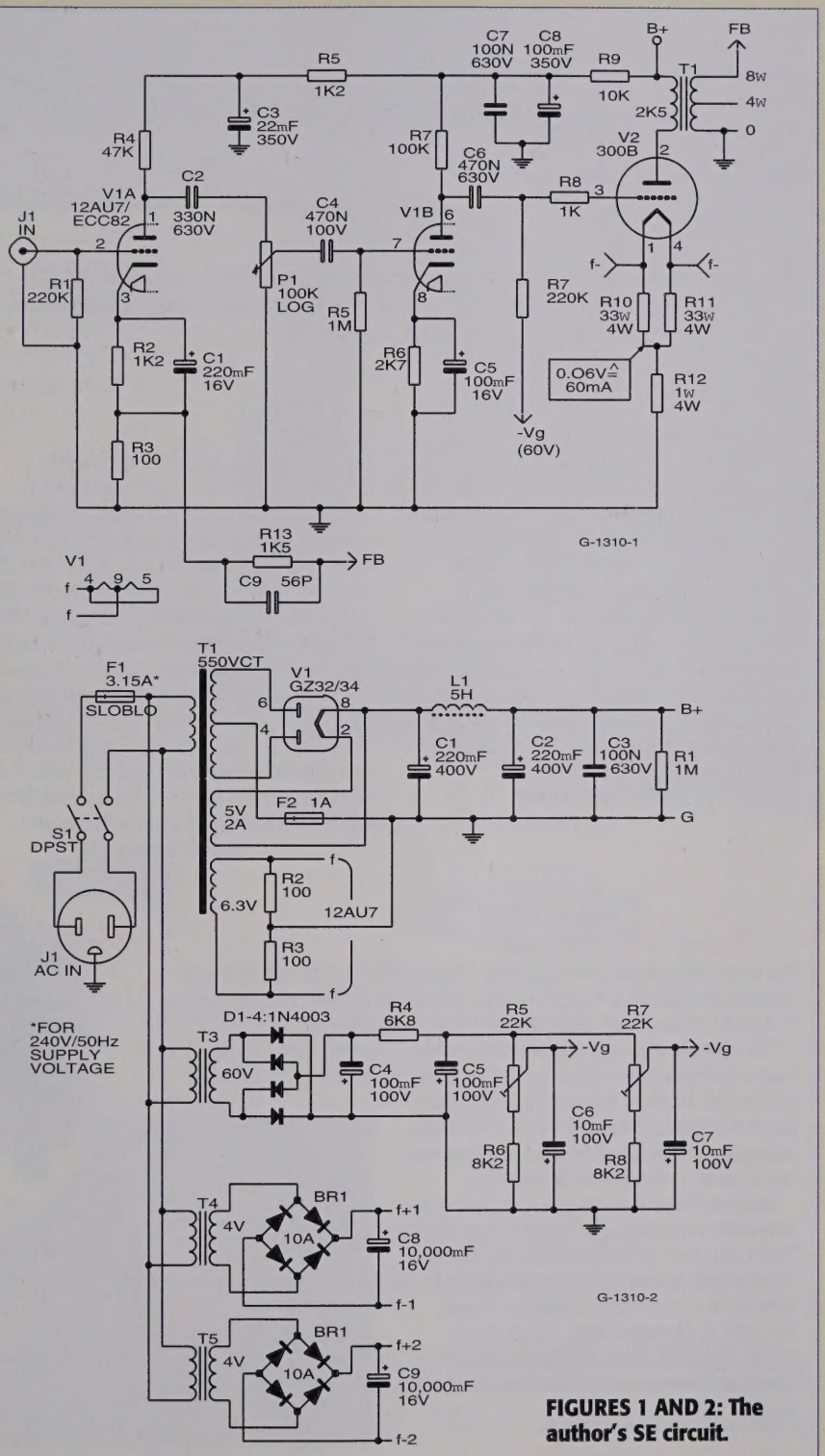
GLASS SHARDS

300B SE AMP

In order to drive a 300B, I tried a few designs, but none satisfied me. This circuit (*Figs. 1* and *2*) sounds great and my Infinity Reference 50 speakers are well supplied with this amp. There are no exotic parts or expensive interstage transformers. ❖

Adolf Oswald
Saaldorf, Germany



FIGURES 1 AND 2: The author's SE circuit.

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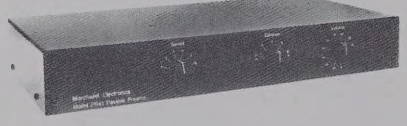

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GLASS CASE

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Reader Service #135

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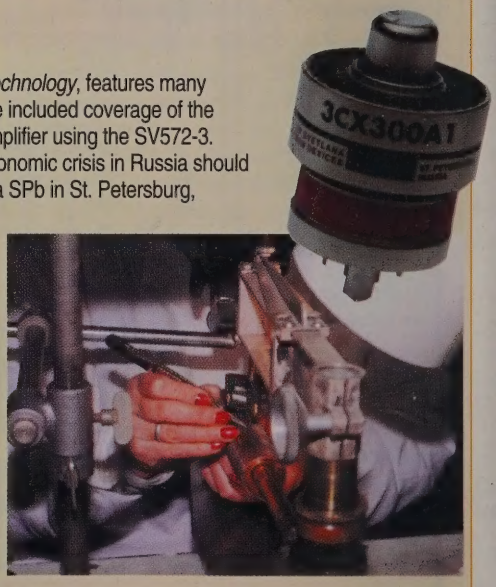
Reader Service #136

■ CAP TESTER

Electronic Design Specialists updated its CapAnalyzer 88 to the CapAnalyzer 88A. It includes test probes for testing both radial and all types of surface-mounted caps with just one hand. A higher DCR range set-alert adjustable up to 500Ω allows you to check both electrolytic and tantalum caps. Added was a QuickESR test for fast ESR-only testing, with the original discharge/DCR test/ESR test mode still available for accurate good-fair-bad testing. It features a one- to five-beep multitone that allows you to know the ESR reading without having to read the 20-segment LED display. Battery life is also improved. Electronic Design Specialists, Inc., 4647 Appalachian St., Boca Raton, FL 33428, (561) 487-6103, Website http://www.eds-inc.com/.

Reader Service #137

⊃ SVETLANA IN THE SPOTLIGHT



The Asian tube-oriented hi-fi magazine, *MJ Audio Technology*, features many Svetlana products in its November issue. One article included coverage of the 3CX300A1 power triode, as well as the Meishinn amplifier using the SV572-3.

The company also announced that the current economic crisis in Russia should have a minimal effect on tube production at Svetlana SPb in St. Petersburg, according to Mr. Farid Rafiee, Chairman of the Board of Svetlana Electron Devices. The factory has vertical integration, meaning that it does not rely on parts produced in other factories.

Svetlana invites you to take a cyber-tour of its manufacturing facility in St. Petersburg by visiting "The Tube Zone" at www.svetlana.com. Click on "What's New" to view a series of photographs recently taken at the plant. Svetlana Devices, Inc., 8200 S. Memorial Pkwy., Huntsville, AL 35802, (256) 882-1344, FAX (256) 880-8077, E-mail info@svetlana.com, Website www.svetlana.com.

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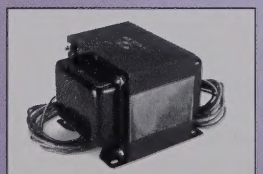

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